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**Comparison of Beam Dynamics Codes 'DDYNZ' and 'TRACEX'.**

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**A. Introduction.**

Two original Los Alamos codes (LINAC and TRACE3D) together with a code used to formulate coupled cavity linac systems, ('DESIGN'), have been modified to allow full data set equivalence for both modes of beam dynamics simulation- 3D linear matrix (TRACE3D) and non-linear multi-particle modes (LINAC).

Fermi versions of these codes are:

fermi(DESIGN)= DISKZ  
fermi(LINAC) = DDYNZ  
fermi(TRAC3D)= TRACEX

This note describes consistency studies between DDYNZ and TRACEX, to verify

- i. beam parameter descriptions (TWISS vs phase space distributions)
- ii. transverse lattice properties, as approximated for accelerated systems from the quad law generated by 'DISKZ'.
- iii. longitudinal dynamics, using a bunch shape matching section designed by TRACEX for minimizing synchrotron shape oscillations in a 805 MHz linac
- iv. predicted space charge effects ,derived from impulse matrixes TRACEX, vs interparticle ring charge force summations used by DDYNZ.

**B. Test Design :**

A coupled cavity 805 MHz linac was designed to match to an existing 200 MHz drift tube linac beam output, assuming the transition to the coupled cavity structure occurred at the fifth (of nine existing) tank of the d.t. linac, at nominal energy 116.5 Mev.

The test design constraints are summarized in Table I. No RF power distribution assumptions were made. Tank lengths of 1 to 2 meters are consistent with transporting beam radii of 7- 10 mm for the transverse beam emittances available from the 200 Mhz d.t. linac.

Table I. Test 805 Mhz Linac Design

Energy range:	116.54 to 400. Mev
Rf Tank constraint :	1.0 meter length, (15% variation)
Maximum Average Ez :	8.0 Mev/meter, constant
Bridge lengths :	1 cell length, constant

Quad lengths	:	8.0 cm. constant
Quad law a	:	a. min.Twiss.beta (80deg.phase advance)
Quad law b	:	b. 45deg. phase advance
Aperture radius	:	1.50 cm.
Transit time factor	:	velocity dependence from SSC design #8
Rf drive phase	:	-32.0 deg. (each tank entrance)
No. of RF tanks	:	52 (4 matching + 48 acceleration)
Total length	:	58.4 meters

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### Input Beam Constraints.

The input beam was defined in the transverse plane from recent 200 MHz d.t. linac data (McCrory). The longitudinal beam description was modified from the McCrory data to achieve matching for a matching section gradient (.81 Mev/m) approximately mid range in the expected 200 MHz bunch size variation.

Table II shows the 116.54 Mev beam inputted to the 805 MHz test structure.

Table II. 116.54 Mev input Beam

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x-plane beta :	4.572	meter
x-plane alpha:	0.837	
y-plane beta :	6.855	meter
y-plane alpha:	0.704	
z-plane beta : (805MHz)	.0480	deg./kev (.0652= McCrory)
z-plane alpha:	-0.240	(0.131= McCrory)
x-plane emittance:	10.	$\pi \cdot \text{mm} \cdot \text{mrad}$ . (unnormalized)
y-plane emittance:	10.	$\pi \cdot \text{mm} \cdot \text{mrad}$ . (unnormalized)
z-plane emittance:	35000.	$\pi \cdot \text{deg} \cdot \text{kev}$ . (805 MHz)

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The test input beam is constrained transversely because it is a FODO channel output from the 200 MHz linac, and longitudinally ,because of the z-plane restoring gradients (2.6Mev/m) present in the 200MHz acceleration process. A fourfold rescaling of bunch size (deg) is required from the frequency change (200  $\rightarrow$  805 MHz ).

The transverse test beam used here implies substantial betatron shape oscillation amplitude, since a FODO channel (in a d.t. linac) when well matched should show x-y beam alphas of opposite sign, within a quad space length of the channel output.(64cm)

However, such a transverse mismatch was used to force the beam simulation

tests to include a severely perturbed quadrupole setting in the matching section, therefore increasing sensitivity to any discrepancies in the two dynamics simulations.

Figures 1 thru 6 show the input beam phase space descriptions, with the correspondence of the particle distributions used in DDYNZ related to the ellipsoid transformed by the TRACEX simulations. The 'TYPE' label indicates the various distribution functions. TYPE=2 is a smooth filling of 6d phase space, closest to a gaussian spacial profile. TYPE 7 is a 4d shell distribution, transversely, and smooth filling in the longitudinal phase space.

#### Phase space units.

TRACEX uses mm.mrad and deg.kev for tranverse and longitudinal phasespace, stored as : BEAMI(6) and EMITTI(3)

DDYNZ converts the (BEAMI,EMITTI) data to cm.rad and deg.Mv

Note that z-plane ellipses are time domain,(phase),in both codes, so that a negative z-plane alpha implies a shrinking drifting bunch, because of the inversion from positive time to positive z-displacements.

#### C. Longitudinal Dynamics.

A four tank (12cell) matching section running as a buncher(phase=-90deg) and with eot= 0.81 Mev/m. was used to match to the accelerating eot=7.0 Mev/m. The required z-plane input beam was determined from a TRACEX matching study, and the corresponding case was simulated with the same system data set using the DDYNZ code. Figures -7- and -8 show the bunch shape oscillations predicted by both dynamics simulations, matched for 30 ma. but suppressing space charge for acceleration from 116 to 400 Mev, simulating low beam current (<<30ma.) bunch transmission.

The DDYNZ multi-particle dynamics were altered from the original single transformation to be identical (in linear order) to the double gap transformations used in TRACEX for the coupled cavity (pi mode) linac dynamics. Both single stage and double stage gap transformations were tested with no differences in the resultant beam simulations. Only a single 'T' factor is used in these simulations.  
The double rf transformations used were:

half gap - x.y defocusing impulse coefficients:

$$kx = ky = - \pi \cdot e \cdot eot [ (1 - \beta^{**2}) \sin(\phi) / 2 + \text{sn.} (1 + \beta^{**2}) \cos(\phi) / \pi ]$$

$$\frac{2 \cdot mc^{**2} \cdot \beta}{\beta}$$

half gap - z-plane focusing impulse coefficients:

$k_z = \pi \cdot e \cdot c \cdot t \cdot [ \sin(\phi) / 2 - s_n \cdot \cos(\phi) / \pi ]$

$\frac{mc^2}{2} \cdot \beta$

where ' $\beta$ ' is the mean bunch velocity/c in the half gap,  
and ' $\phi$ ' is the bunch centroid phase.  
and ' $s_n$ ' is +1 in the first half gap and -1 in the second half gap

The resulting bunch shape matching predicted by particle simulation (DDYNZ) corresponds well with that predicted by the linear TRACEX simulation, for several assumed particle distributions, using 1000 particle samples. The residual shape oscillations in the DDYNZ simulations are statistical in nature.

Sensitivity to beam mismatch is consistently predicted by both codes.

#### Longitudinal Test Runs:

Two test systems were run- i. a bunch shaper section of 8 tanks, with half synchro wavelength was studied to compare the space charge effects predicted by both dynamics and ii. the original 52 coupled cavity system, consisting of a 4 tank bunch matcher, and 48 tanks of acceleration to 400 Mev.

Figures 11 thru 14 illustrate the effect on beam bunch, when transported through about 180 deg. of phase advance, in the 8 tank simulation. Because the space charge forces, relative to the external rf forces are maximum at the point of bunch matching (90deg. of advance) this simulation provided a space charge consistency check at the most sensitive area in the 400 Mev. linac design. Beam currents of 120 and 240 ma. were simulated, with consistent phase envelope shifts predicted by both codes. Space charge effects are small, even at these charge levels.

Though the DDYNZ dynamics simulations sample space charge effects on a tank (1 meter, here) basis, as opposed to a half cell basis by TRACEX, no significant discrepancy is seen in this test, for the coarse sampling in the particle sum approach- a requirement necessitated by DDYNZ execution time considerations.

The full linac system was run, with the same input file for both codes, at 30 ma ( $XI=120.$ ), using the test input beam. Figures -9- and 10- show the resulting bunch shape matching predicted by particle simulation (DDYNZ) corresponds well with that predicted by the linear TRACEX simulation, for several assumed particle distributions, using 1000 particle samples. The residual shape oscillations in the DDYNZ simulations are statistical in nature.

Sensitivity to beam mismatch is consistently predicted by both codes.

#### D. Transverse Dynamics. (FODO example)

Design of a FODO channel for an accelerating system was performed in the code DISK by splicing FODO half cells together, neglecting momentum damping. Using a tuning parameter 'QLAW', a choice of TWISS optical constraint is calculated, according to:

-either-

QLAW=0 code uses user defined quad gradients  
 -or-  
 -a stability diagram search is performed, accounting for beam momentum  
 magnetic rigidity variation to produce :

- =1 minimum TWISS BETA in both plane ( approx. 80deg. phase adv, this test
- =2 fixed phase advance, x.and.y.plane independently
- =3 fixed TWISS beta and waist (defocusing-plane) beta
- =4 momentum scaled TWISS beta

Table III shows the various transverse dynamics parameters found in the test linac system described above.

Table III. Tranverse Force Dependencies.

tank length - 1 meter

FODO channel period - 2 meters (1 meter quad to quad)

Quad length - 8 cm

quad gradient - 3. kg/cm. (4.5 kg at 1.5cm pole tip)

Net radial impulse per 2meters at energy =	116 Mev	400 Mev.
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KQ ( 3 kg/cm)	= 21.0	10.5 m**-
quad restoring impulse= KQ * .08 *cancel	= 3.36	1.68
rf defocusing impulse= 2*KRF* 12cell/13 cells	= .46	0.06
percent (rf/quad)	= 13.5%	3.5%

where -->

$$KQ = \text{grad} / B.\rho$$

$$KRF = \pi \cdot e \cdot \sin(\phi) \cdot T_E \cdot (938 \cdot \text{wavel} \cdot (\beta \cdot \gamma)^{1/2})^3$$

cancel = 0.5 (avge. impulse.factor assuming 50% cancellation from defocusing quad in FODO lattice)

The importance of the Rf defocusing forces is evident at the entrance energy where it represents 13% of the total restoring impulse available from the FODO chanr For comparison, the space charge defocusing impulse is 2 % of the net FODO impulse, for a 30ma. beam, occupying every fourth bucket at 116 Mev.

#### FODO Channel Design.

The DISKZ code allows a first pass design to be synthesized, using the 'QLAW' par to specify a constraint, typically phase advance or Twiss beta. Both momentum damping

and space charge are neglected, for the 1st pass quad design, but FODO period discontinuities (typically 15% steps) are accounted for.

Figures 14- thru-17 show the tuned FODO channel, using only the first four quadrupole to match the 200 MHz beam into the 805 MHz structure. No acceleration section quadrupole tuned, indicating a good first pass quad law produced by the DISKZ code. Both dynamics are in agreement, to within .5mm, in predicting transverse shape oscillations, at 30ma. currents. A tune with slight mismatch in the -y-plane was used to correlate the mismatch sensitivity. Both dynamics modes verified the mismatch correctly.

Transverse space charge effects for currents of 120 and 240 ma. are shown in figures -18 and -19, for a quad law tune matched for 30 ma. of beam. Major transverse envelope discrepancies arise at these current levels, because of emittance blow-ups from the space charge effects, as discussed below.

#### E. Emittance blow-up Effects.

TRACEX can monitor only the chromatic coupling effects in the quadrupole channel and the phase coupling effects in the RF gap channel. Both these effects were negligible when the transverse emittance was monitored along the beam axis by TRACEX. However, the non-linear effects of space charge appear as significant emittance blow-up, at current levels of 120- 240 ma. as simulated by DDYNZ.

Figures -18 and -19 show the x-plane 100% beam envelope for 240 ma. beam. The TRACE space charge mismatch appears to damp out at high energy, while the DDYNZ simulation indicates a pronounced remaining mismatch, that is caused by emittance blow-up. Normalized x-plane emittance was monitored by DDYNZ, both at RMS and 100% levels.

Figure 21 shows the blowups resulting from 30 and 240 ma. of beam. While the RMS blow-ups are small (10%), the x-plane halo (100%) fitted ellipse indicates blow-ups of 20- 80%, consistent with the x-plane 100% envelopes that were predicted by DDYNZ to have significant halos in the high energy tanks. These regions would typically contain 5-10 % of the beam population.

The longitudinal emittance blow-up at these beam currents are shown in figure-22.

The 100% z-plane emittance has blow-ups of 10 and 25% for 30 and 240 ma. of beam. It would appear that small z-plane dilution from space charge results from the smooth bunch matching produced by the phase rotation system.

#### F. Conclusions.

A coupled cavity linac, and matching section can be synthesized quickly, with minimum design tuning, by using the 1st pass code DISKZ, to make up the initial system data set. Further tuning of the data set by the TRACEX code, can bring in linear space charge and momentum damping effects. Additional non-linear effects, or space charge effects arising from non-uniform particle densities can be assessed by using the trimmed TRACEX data set as input to the particle code DDYNZ. Thus a well understood and consistent beam dynamics study can be performed for system evaluation.

The results of this test case study indicated that both dynamics simulation codes we

in good agreement, in the regime of small non-linear effects, and small space charge forces. The relatively quiet transverse envelopes obtained with only 4quad tuning indicate that the 1st pass QLAW gradient laws were adequate in producing smooth beam transport for an accelerated beam.

Significant emittance blow-up appears in the DDYNZ simulation at currents of 120-240 ma., affecting the 10-20% halo population in the beam phase space.

No significant blow-ups are predicted for the 30-60 ma space charge region, for the test linac design simulated in these studies.

The two sample beam distributions appear to have large emittance dilution, at the 90% level. A study by Sacherer (1), using a 50 Mev. bunched beam showed that non-linear space charge dilutions of 5-10% appeared for beam currents of 100-200 ma. However, the bunch size in this case was 4-6 times larger in all 3 dimensions, implying charge densities 60 -200 times smaller than the test linac design studied here. Blow-up factors for the 90% envelopes for 2 different particle distributions(uniform 6d ellipsoid fill ,and kv 4d transverse,with uniform z phase space) were typically 3-4 , ie ,the 10% transverse halo population were enclosed by ellipses 3-4 times larger than the original input beam ellipse. Thus, studies of channel phase advance vs beam distributions can be utilized to assess space charge dilutions arising from resonance instabilities if present in the linac system design.

#### References.

1. F.J. Sacherer et al.(Proc. of IEEE,-NS-18,1971, p1066.

#### APPENDIX A.

#### DISKZ CODE (Synthesis of Coupled Cavity Linac)

##### Function-

DISKZ formulates the rf tank design, using given transit time data, field gradient and effective synchronous phase. A tank of 'nc' coupled cavity cells is designed by an algorithm that determines an effective synchronous phase and energy, for each tank, or, some integer (KABB) set of tanks with common cell length.

The cell length is varied until the bunch center phase drift, caused by departure of the bunch velocity from the synchronous velocity (geometrical beta) is exactly cancelled out when the bunch leaves the KABBth ncell tank. This means the bunch center sees the same drive phase (phid) in the first and last cells of the KABB tank array.

$$\text{phid}(1) = \text{phid}(\text{KABB} \times \text{ncell}) = \text{phis} \text{ (input syn.phase)}$$

Constraints on the average electric field ( $E_z$ ), are recognized by the limit parameter EKX, which defines the maximum surface field used in the linac tank design. Beam velocity dependent structure parameters are generated (transit time factor, ztt, EoT,) so that

power dissipation is monitored as the design is laid out. Structure data is entered as 6 expansion coefficients of the 'beta' dependence of the set [T,ZTT,EMULT], where the ope average axial E field becomes:

$$E_z = E_{KX}/EMULT$$

where  $E_{KX}$  (Mv/m) is the maximum surface field derived from a Kirpatrick thresh and EMULT is the cell modelling ratio of max.surface field to average axial E-fie

DISKZ can synthesize tank lattices in which several tanks, separated by coupling cells, are designed with the same cell length. This is useful for higher energy modules, when the bucket boundaries allow larger energy departures from the synchronou energy (defined by geometrical beta), ie many fixed beta cells, without non-linear z-plane phase motion. In this case, the quadrupole (coupling) cells

are placed within a fixed beta structure, by replacing an accelerating cell with a coupling mode cell, to house the focusing magnet. Since the synchronous phid condition is achieved only after traversing 'KABB' tanks, a larger phase lag can occur within the module, unless compensating phase shifts are introduced by coupling cell length adjustments.

DISKZ will also design a first pass quadrupole gradient distribution, using an algor searches the stability diagram for the net restoring forces in a FODO channel that con significant RF defocusing lenses. Typically 20 to 40 rf lenses are present before a f element is presented to the beam.

### Diskz Input-

#### 2 namelists - \$design and \$sexion

##### System launch parameters- \$design

\$design	NSEC =	no. of rf sections
\$design	FREQ =	(no. of tanks to be determined by DISKZ synthsis
\$design	WINIT =	RF. drive frequency ((MHz))
\$design	NBRIDE =	initial beam energy (Mev)
\$design	DCMA=	no.of.rf.cells/couplingmodule (odd integer)
\$design	KBUX=	dc beam current (ma.)
\$design	QSIGN=	bucket duty factor.(beam in every KBUX bucket)
\$design	QRES =	sign of first quadrupole gradient
\$design	QUPS =	resolution of stability search(degrees)
		quad.gradient.scale.upfactor (%per.momentum.doublin
		(for QLAW=0 inputted gradient)
\$design	QLBEG=	2xlength of first quad (cm)
\$design	HPBEG=	gradient of first quad (abs(kg/cm))
\$design	TFADX=	x-plane phase advance (deg)
\$design	TFADY=	Y-plane phase advance (deg)
\$design	BXBEG=	MAX. Twiss beta (cm.)
\$design	BYBEG=	MIN. Twiss beta (cm.)
\$design	QLAW =	quad.gradient law
\$design	LATTQ = 1,2	quad.lattice(FODO.OR.DOUBLET)

where-->>>

QLAW= 0	grad = input x (1.+QLUPS) X energy ratio
QLAW= 1	grad = hp(min.Twiss.betas)
QLAW= 2	grad = hp(tfadx,tfady) fixed phase advance
QLAW= 3	grad = hp(hpbegx,hpbegy)fixed twiss beta(x.and.y)
QLAW= 4	grad = hp(mom.scaled.twiss.betas) (beta=hpbeg x momentum ratio)

Structure data ----->>>

\$design	MODE = cavity.field.data.flag
	MODE = 0 (E0t='Ez'.inputted,for rough design)
	MODE = 1 ((scc.structure.data))
	MODE = 2 ((daw.structure.data))
	EKX = max.surface.field(Mv/m)-->'Ez'
if	EKX = 0.0--->>use.inputted.'Ez' .

Power constraints ----->>>

PTX =	max.total.power.dissipation per tank
	( sets.power.level.for.'PTRIM' adjust
PTRIM=	0 (no.power.trim)
PTRIM=	1,2,3= (NCELL,EKX,PHIS)trimmed

Section parameters - \$sexion namelist

A 'section' in DISKZ must contain an integer no. of power MODULES, typically 10. User control of the cell distribution, can quickly define where the segmentation of modules should occur, to satisfy power feed point requirements, since each tank power consumption is monitored. Once a rough power distribution is determined, power trims within a section (or module) can be triggered via the 'PTRIM' parameter, using the sec (module) power per tank limit (PTX).

Note that an 'NCELL' trim, must satisfy parity (odd integer) if designing a DAW structure, because of the end half-cells produced by the 'tee' bi periodic symmetry.

A section is generated by designing 'K' Tanks, of NC cells, separated by 'NBRIDE' coupling cells. Cell lengths are held fixed for 'KABB' tanks. Section boundaries should be adjusted by redefining section output energies (WF) so that 'K' no. of tanks is correct for the power MODULE (segmentation) and focusing requirements.

'PHID' is constant,(unless power trimmed)

'K' is determined when the section output energy exceeds the estimate value 'WF' (mev).

If section input energy = output energy, a single tank bunching section is designed.

\$sexion	NC = no. of cells per tank
\$sexion	WF = final (minimum) beam energy(Mev)
\$sexion	EKX = max.surface.field (Mev/m)
\$sexion	EZ = average axial field=ev/m)
	(EZ inputted if EKX=0,ie no. max. surface field defined)
\$sexion	PHIS = section entrance drive phase (deg)
	= exit drive phase every 'KABB' tanks (for synch.particle)

\$sexion HP = quad.gradient (kg/cm) (absolute value)  
\$sexion QL = quad.length(cm)-downstream.bridge.cell.only

local overwrites of the \$design parameters QLAW,NBRIDE,KABB,BXBEG,BYBEG  
TFADX,TFADY  
EKX,PTX,PTRIM  
are available in the \$sexion namelist.

#### Section boundaries:

Rf drive phase is constant within section(module)boundaries.  
The beam synchronous phase is 'phid' entering & leaving each 'KABB'  
set of tanks, within the module. Figure \_\_\_\_\_ illustrates the interdependencies  
of these parameters, and the resulting phase lag seen by the bunch center as it  
traverses the tanks in a section (MODULE).

#### QUAD LATTICE ALGORITHM-

The design of a first pass quadrupole gradient law is  
accomplished by routines DSNQUAD (fodo),DSNQLAT(doublet).  
Both algorithms design a full two tank quad lattice, by splicing  
an approximated half cell (one tank) lattice to the neighboring  
half cell. For the FODO design this simply uses the mirror  
symmetry of the approximated full cell. For the doublet case,  
a full cell approximation is constructed by adding the transformation  
matrix from the alternate plane half cell, to make a full  
approximated cell. Stability searches trap out the required  
Twiss property, ie, beta, phase advance, or minimum beta.

At present (dec.87.) the FODO algorithm allows 2 dimensional  
searches, ie, split tuning x.and.y planes independently.  
The doublet algorithm presently allows only 1 dimensional  
tuning.

#### DISKZ output-

DISKZ produces an ascii data set (tape29) that is a fortran namelist (\$data)  
format description of the synthesized linac lattice, which can be read as an input  
(tape 30) file by TRACE3D, or as DDYNZ input, read as tape31  
when triggered by the flag ITAPE=31, in the tape10 namelist '\$dset'.  
Note that DISKZ sends tank output energy data in A(5,n), originally unused by TRACE3D.  
However, TRACE3D now records the same information in A(5,n), so that beam energy  
bookkeeping is facilitated during the TRACE3D trimming.

DISKZ printed output shows the quad channel lattice parameters, and z-plane phase  
advance information.

DISKZ graphics shows transit time vs. energy data, quad gradient along optical axis, contains code to show the current rf fixed bucket, at any linac tank, to assess the z-plane dynamics. (local bucket plots are currently suppressed. Oct.87)

Table IV shows an input file used by DISKZ to generate the test linac described here.

Table IV. Sample DISKZ input

```
$DESIGN NSEC=9, NBRIDE=1, FREQ=805., WINIT=116.54,
    TFADX=45., TFADY=45.,
    QRES=0.5, LATTQ=1,
    BYBEG=100., BXBEG=466.,
    MODE=1, PTX=0., EKX=0., PTRIM=0.,
    DCMA=0., KBUX=4, QF=1., QLAW=0., QSIGN=-1., HPBEG=3.000, SEND
$SEXION NC=12, WF=116.540, EZ=0.940, PHIS=-90., QL=8., HP=3.0, SEND
$SEXION NC=12, WF=116.540, EZ=0.940, PHIS=-90., HP=3.000, SEND
$SEXION NC=12, WF=116.540, EZ=0.940, PHIS=-90., HP=3.000, SEND
$SEXION NC=12, WF=116.540, EZ=0.940, PHIS=-90., HP=3.0, SEND
$SEXION NC=12, WF=123.000, EZ=8.00, PHIS=-32., HP=3.0, QLAW=2., SEND
$SEXION NC=11, WF=157.198, KABB=1, PHIS=-32., SEND
$SEXION NC=10, WF=197.828, KABB=1, PHIS=-32., SEND
$SEXION NC=9, WF=273.231, KABB=1, PHIS=-32., SEND
$SEXION NC=8, WF=401.491, KABB=1, PHIS=-32., SEND
$DESIGN NSEC=0 SEND
```

APPENDIX B. DDYNZ CODE (Particle Dynamics in Coupled Cavity Linac)

Function-

DDYNZ is a modified version of the Los Alamos particle dynamics code LINAC. The Fermi Version allows coupled cavity data sets written in TRACEX format to be used files. DDYNZ can also read PARMILA data sets (tape6) that are descriptions of Drift Tube linac output beams, and beam envelope/emittance summaries from the previous d.t. DDYNZ allows 1000 particles to be tracked, with nonlinear (chromatic, coupling, and space charge) effects included.

Originally space charge effects were monitored by averaging over 1 tank, sampling at tank center, where the beam is approximately round in a matched FODO channel. DDYNZ samples space charge forces, additionally, at each bridge coupler quad, where a small waist occurs in the defocusing plane, to provide better sensitivity to elliptical beam cross sections.

However, beam charge is distributed over a cylindrical mesh (10 x 20 grid points) to allow electric field estimates via elliptic functions for ring charges. Thus, the intra-particle force is smoothed out, avoiding large angle scatters, at the expense of sensitivity in beams with high x-y aspect ratios.

All space charge impulses are calculated in the CM frame, and then are transformed to the LAB system using

the Lorentz transformations for the 3 momentum components.

DDYNZ input -

DDYNZ has three input files--

Tape10 - ascii user data set (\$DSET,\$RUN,\$INP)  
Tape31 - ascii linac data set (\$DATA)=TRACEX input  
Tape6 - binary PARMILA data set (5 records)

(Tape1 and tape7 are obsolete inputs )

Tape10 - controls dataset, particle distribution, and graphics flags

\$DSET ITAPE= 31 (use TRACEX system format) =7 (old format)  
\$RUN NPOINTS= (1000) no. of particles to be tracked  
\$RUN NTYPE= ? various 6d phase space distributions  
\$RUN NTYPE= 1 smooth fill 3 phase spaces independently  
\$RUN NTYPE= 2 smooth fill 6d ellipsoid  
\$RUN NTYPE= 5 smooth fill 4d x.y ellipsoid  
\$RUN NTYPE= 6 smooth fill 2d z ellipsoid independently  
\$RUN NTYPE= 7 shell fill 4d x.y ellipsoid  
\$RUN NTYPE= 8 smooth fill 2d z ellipsoid independently  
\$RUN NTYPE= 9 smooth fill 3d x.y.z spacial ellipsoid  
\$RUN NTYPE= 13 smooth fill each angular coord. independently  
\$RUN NTYPE= beam 6d distribution from PARMILA(Tape6)

(NTYPES 3,4,6,9 are currently suppressed)

\$RUN IEND = 0 read \$INP namelist  
\$RUN IEND = 1 end.of.tape10.input

\$INP IGRAF = 1 graphics.flag.  
\$INP NURUN = N Nth dump of PARMILA.tape6.data set  
\$INP AX,BX,EX,AY,BY,EY,AZ,BY,EZ=(alpha,beta,emittance)  
(currently obsolete by BEAMI(6),EMITI(3), from \$DATA (tape31) ,

Tape31 - coupled cavity system data  
using TRACEX format - namelist \$data

\$DATA NELTOT = no. of transport elements in system

```

$DATA FREQ = RF frequency(MHz)
$DATA XI = beam current(ma.)Xbucket.duty.factor
$DATA W = input beam energy(Mev)
$DATA BEAMI(6),EMITI(3)=input beam specification
$DATA NT(neletot),A(5,neletot)=transport.data.set(TRACEX.format)
.....

```

\*see TRACEX users guide for descriptions of NT(i),A(5,i)

## APPENDIX C. TRACEX CODE (Matrix Dynamics for Coupled Cavity Linac)

### TRACE3D function- (original code)

TRACE3D is a matrix formulation of beam transport dynamics, with provisions for many beam transport calculations including:

- a. Chromatic and bunch size coupling to transverse emittance growth
- b. linear 3D space charge effects
- c. coupled cavity beam elements
- d. matching algorithms that search for TWISS parameters (local periodic cell) or attempt to tune transport elements to satisfy the entrance (match to a periodic system, for a given inputed beam.

### 'TRACEX'.version-

The Fermi version of this code (TRACEX) contains a search algorithm (QTRIM) that allows trimming of transport elements (typically quadrupole and cavity gradients) to minimize beam shape oscillations (improve beam match) for quasi periodic systems, having small departures from periodicity, either smooth or step like. Shape oscillation amplitudes (betatron or synchrotron) are integrated to produce an error function that is minimized.

'QTRIM' can make a coarse trim to bring an initial gradient to reasonable ranges for the multi parameter 'MATCH' command to converge. Alternately, a fine tuneup occurs with this algorithm by applying it sequentially down a roughly tuned beam line.

### Command List-

A full command list ,including Fermi modifications is given here,as a mini TRACEX users guide.

- |     |         |  |
|-----|---------|--|
| 'A' | and 'D' | - add .or. delete transport element  |
| 'B' |         | - show contents of BEAMI(6),and HOLD(5)  |
| 'C' |         | - change -N-elements-Range[Nbeg-Nfin].or.just.show   |
| 'E' |         | - exit TRACEX  |
| 'F' |         | - phase advance from n1 to n2  |
| 'G' |         | - new envelope plot(from ne1 to ne2)   |
| 'T' |         | - over.plot (from ne1 to ne2)<br>(beam envelopes are chosen by flags [sx,sy,sz] in \$data) |
| 'H' |         | - toggle graphics(batch.or.interactive)  |
| 'I' |         | - also show envelope plot flags<br>- '\$DATA'.entry+scratch.pad.update+reboot.data.options |
|     |         | - Use 'I' to set envelope plot switches -sx.or.sy.or.sz=1                                  |

- after \$data update, TRACEX asks for TAPE10 update,.or.  
else,allows a complete reboot of \$data, from TAPE30.

'J'	- ellipse.projections(currently.suspended)
'L'	- ellipse.gen.via.3-profile.samples
'M'	- matching.algorithm.via.MT.parameter
'O'	- show.current.mismatch
'P'	- show.current.beam,transport.data.
'Q'	- use.'QTRIM'algorithm.to.minimize.shape.oscillations
'R'	- show.current.-R-matrix (nel1 to nel2)
'S'.or.'U'	- save.or.replace.BEAMI.and.sigma.matrix
'W'	- show.phase.and.energy.data
'X'	- show.help.menus
'Z'	- show.modified.sigma.matrix

'QTRIM' input nomenclature-

Command 'Q' produces 2 queries, on the screen-->>>

i. enter MTRIM, MKUPL, MSPAC

- MTRIM is element seq.# for 1st tuned tank
- MTRIM = 0 means quad trimming(transverse)
- MKUPL is no. of tanks to be tuned together
- MSPAC is no. of elements to next tuned tank
- JIMU is quad seq.# to be gradient tuned  
(if transverse.trimming)

ii. enter JIMU,JFODO,DIFF

also

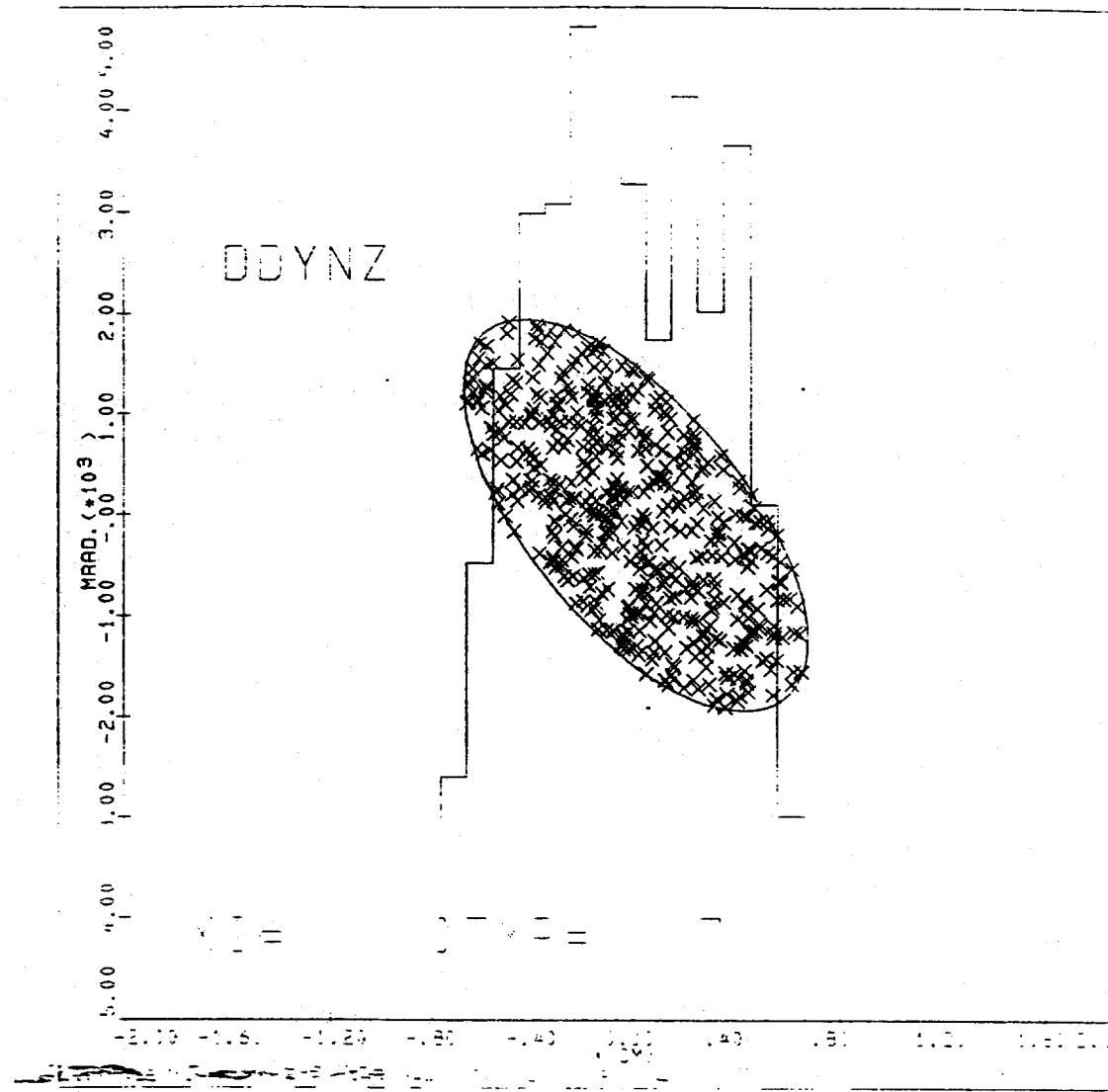
- JIMU is quad seq.# where shape osc.integration
- JFODO is no. of elements in a FODO period (=10)
- DIFF is fractional change in tuned parameter

note- only 1 quad is trimmed,while MKUPL tanks can be trimmed.

.....dec.10.87.  
file=tm24 (90423-cdc)

Figure #1

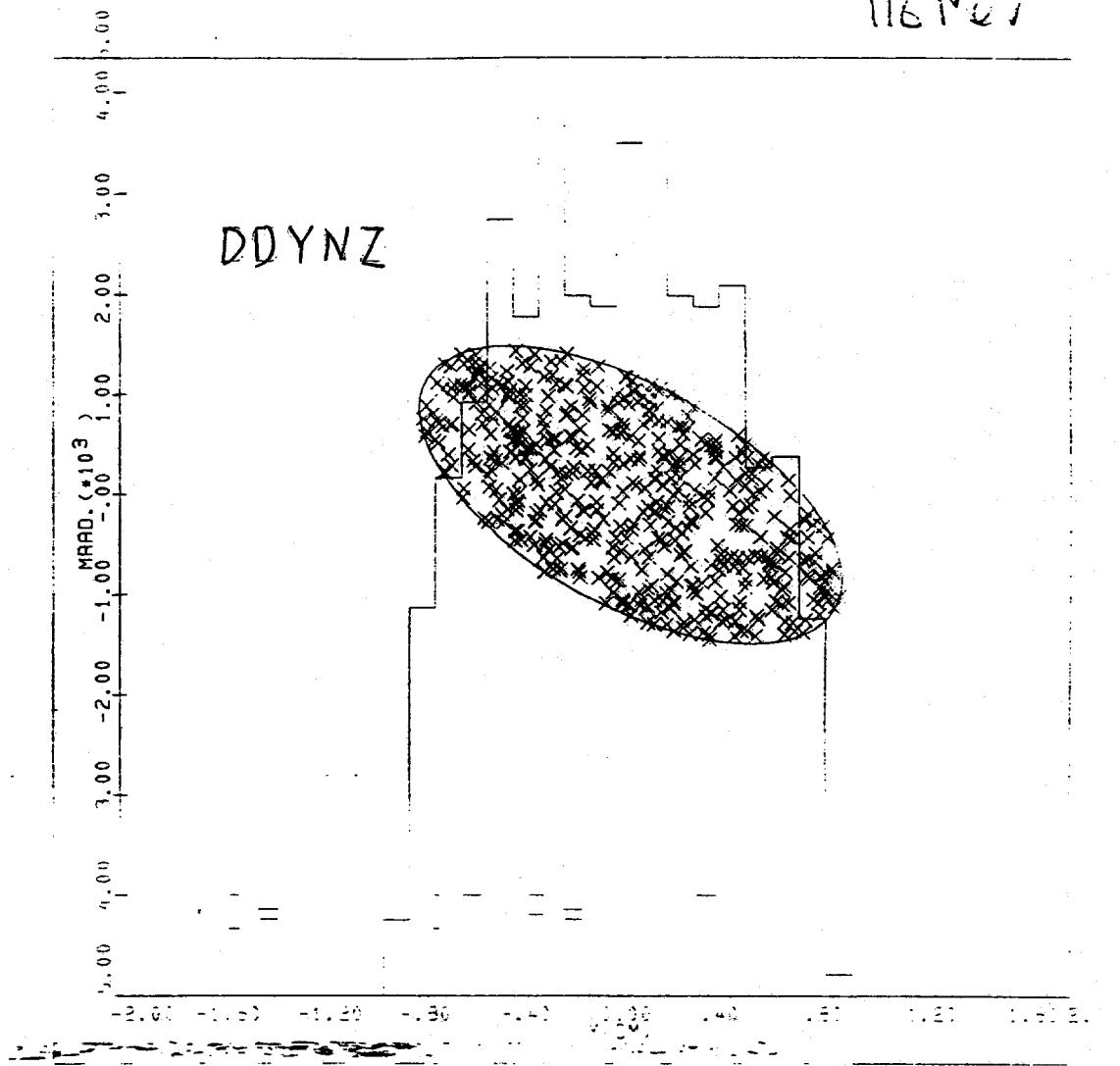
116 MeV



X-plane phase space ellipse (TRACE)  
vs. particle distribution (DDYNZ)  
(MCORY TANK-5 output)

FIGURE \* 2.

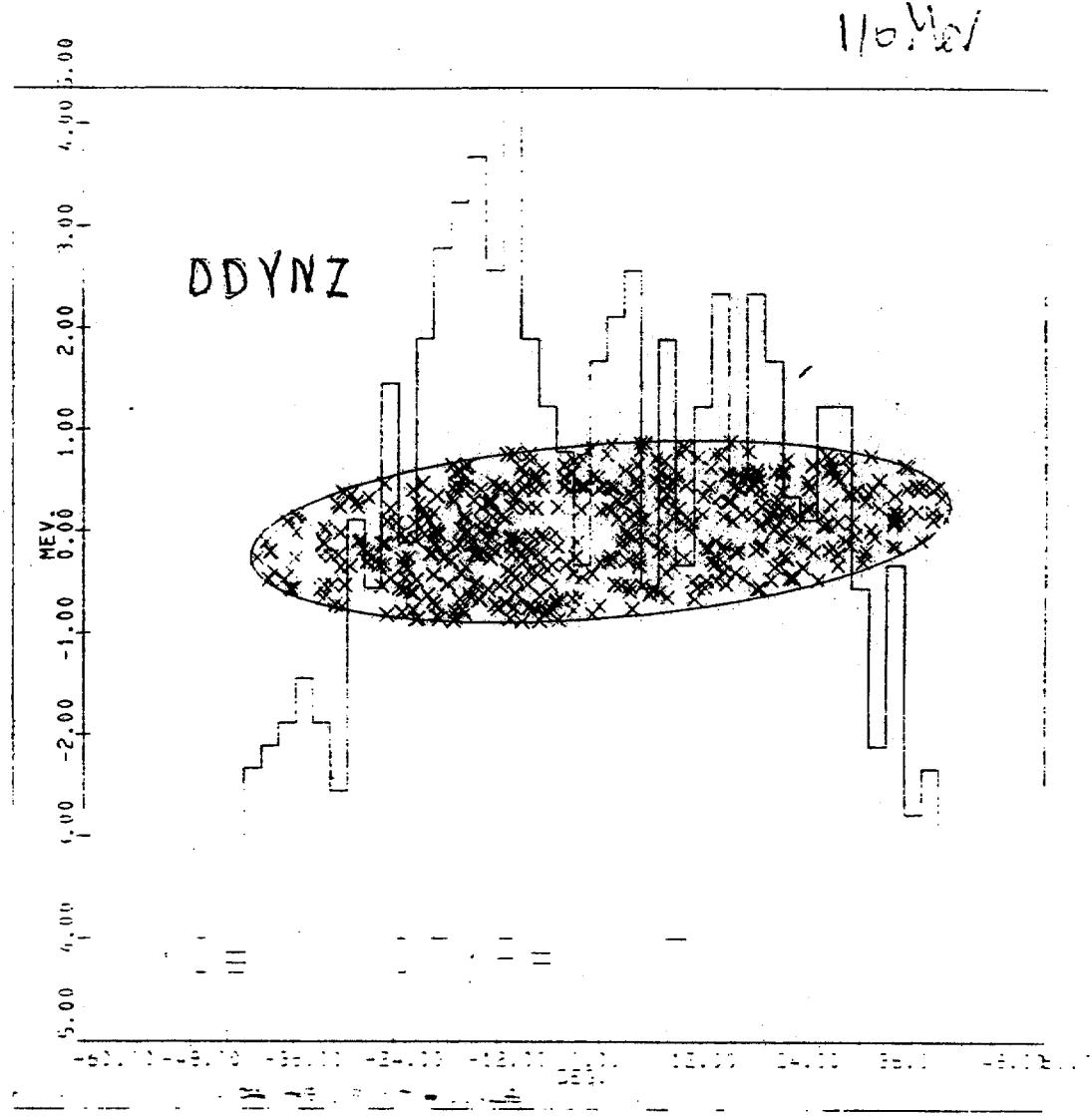
116 MeV



Type 7 = KY. (4D shell)

+ uniform in  $Z-Z'$

FIGURE #3.

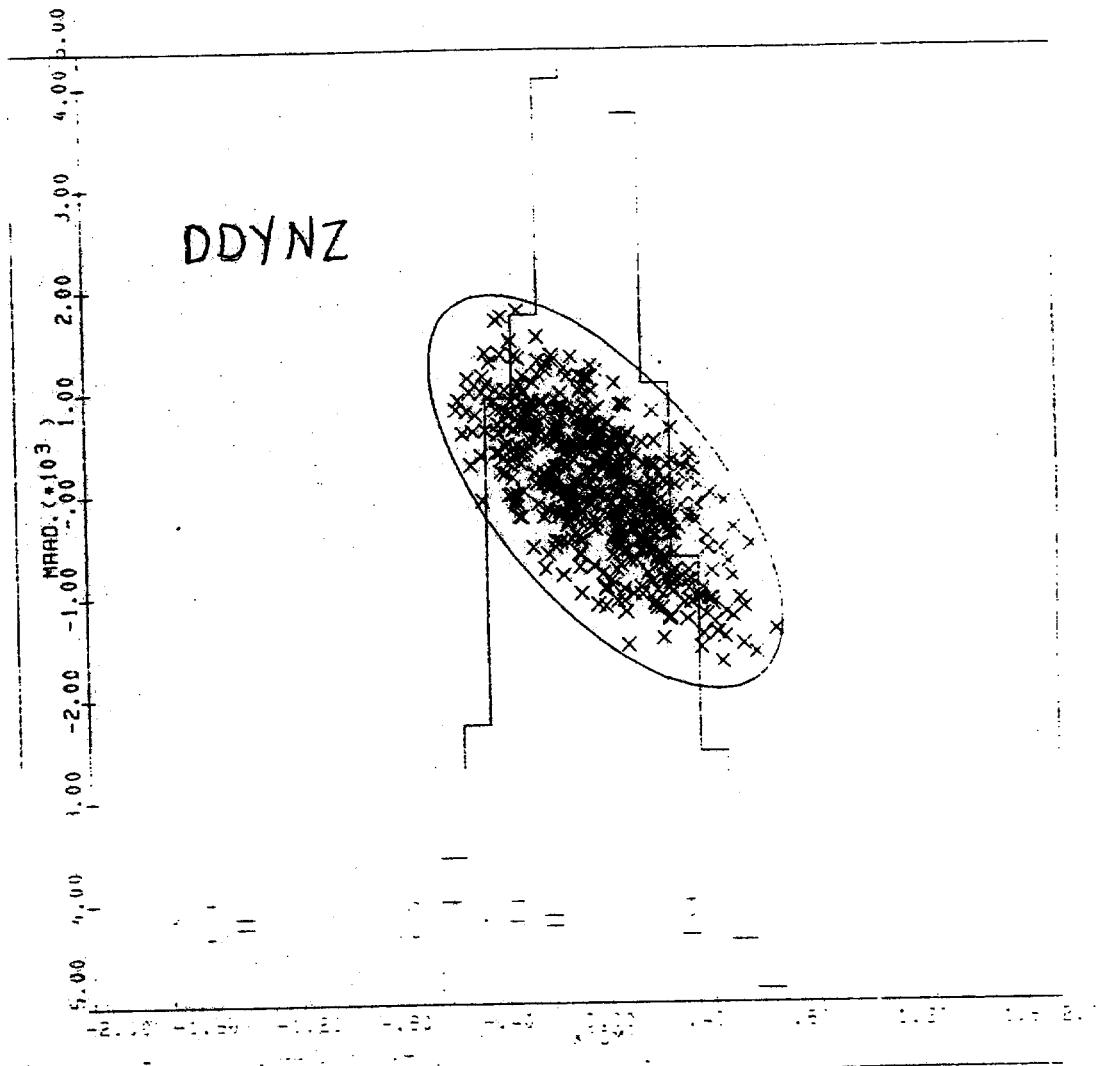


$\Delta E \rightarrow \Delta \Phi$  plane

$$\beta = .048 \text{ deg/k.v.}$$

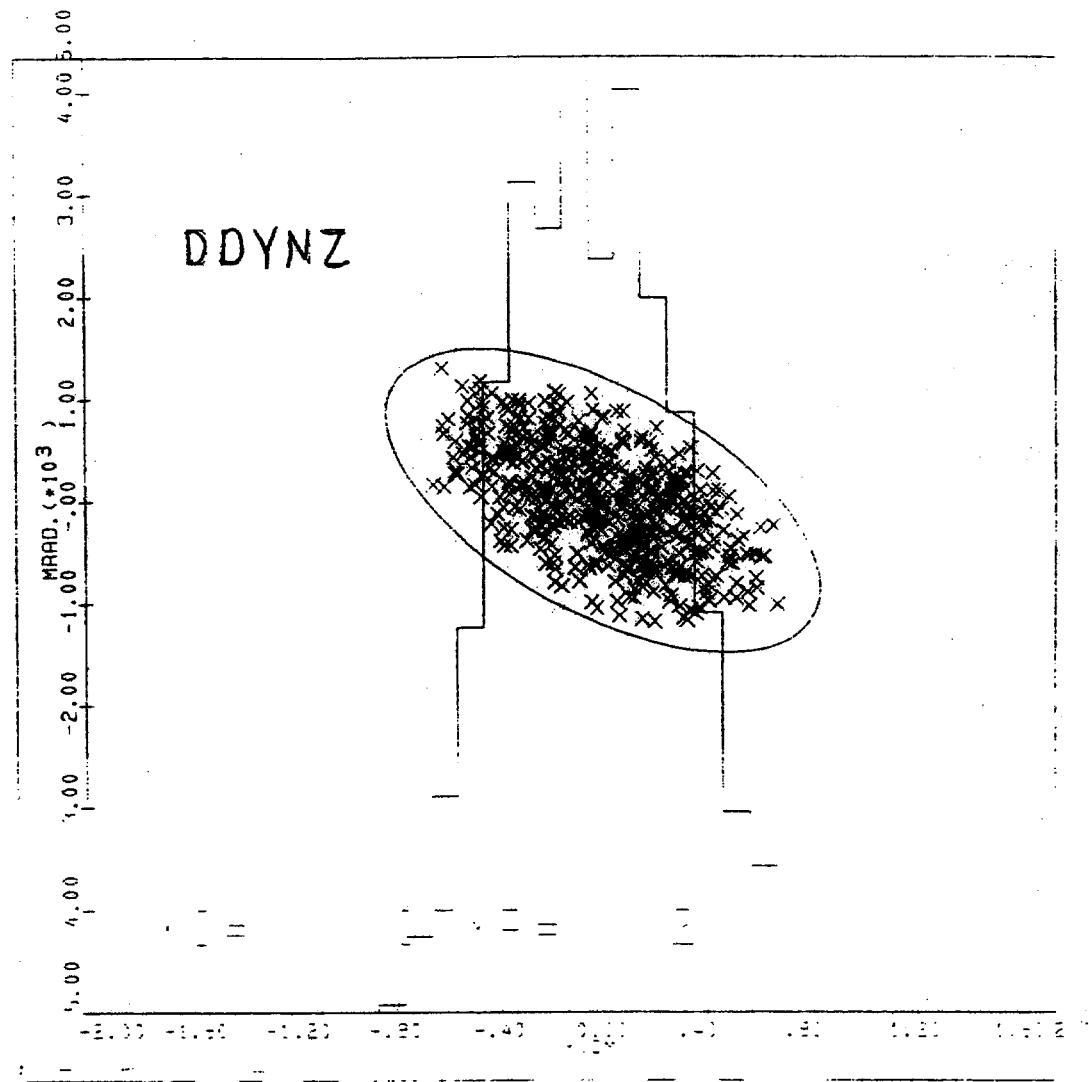
$$\alpha = -0.24 \text{ (time dilation)}$$

FIGURE #4



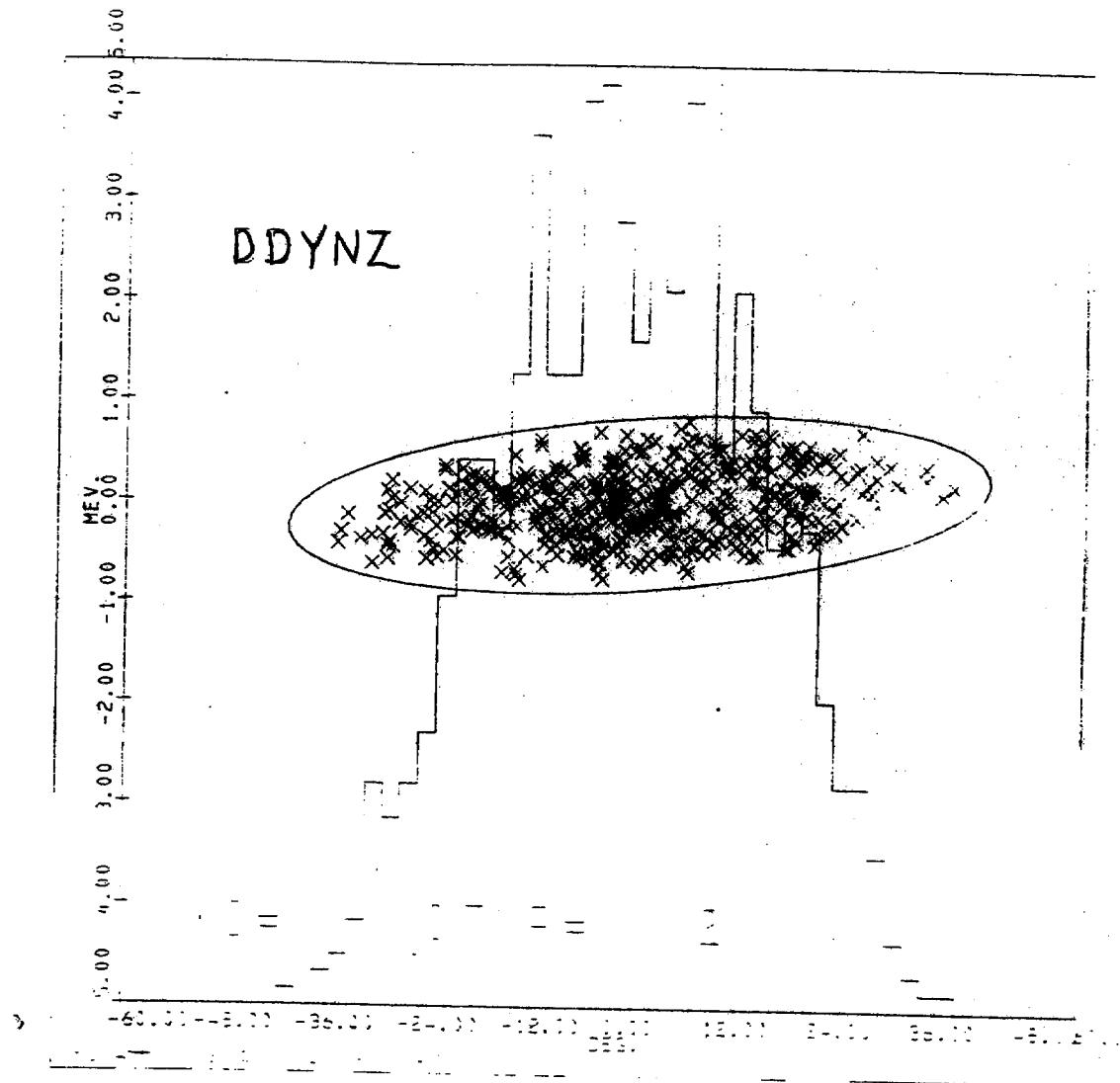
Type = 2. Distribution  
uniform 6D-hyp. ellipsoid.

FIGURE # 5.



Y-plane: TRACEX vs. DDYNZ  
test beam input

Figure #6.



"quasi" gaussian (6D uniform)

FIGURE #7

Symmetrical oscillating fig.

low beam currents

(time to match = 30ma.)

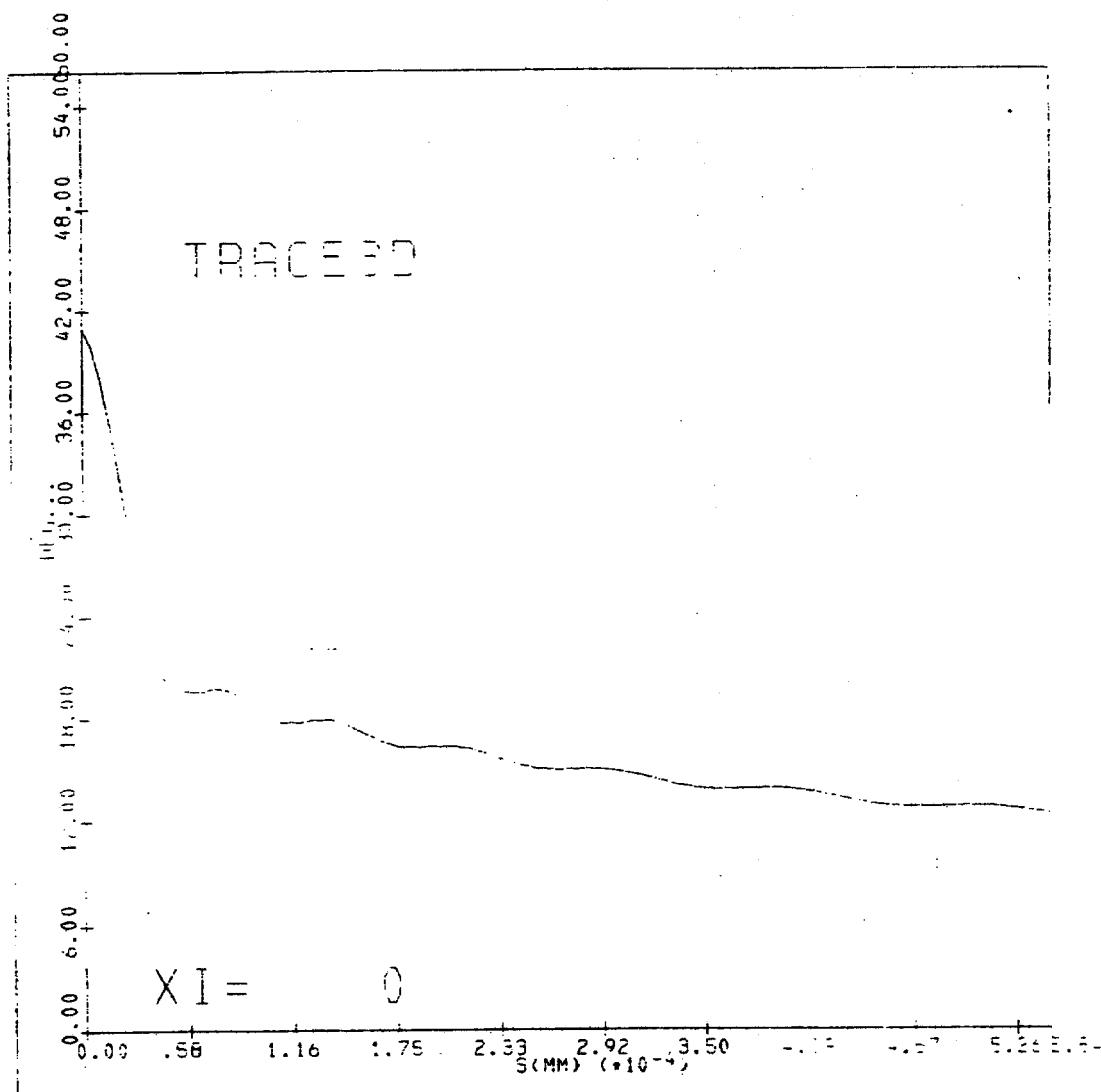


FIGURE #3

(same as Figure #7)

(1000 particles)

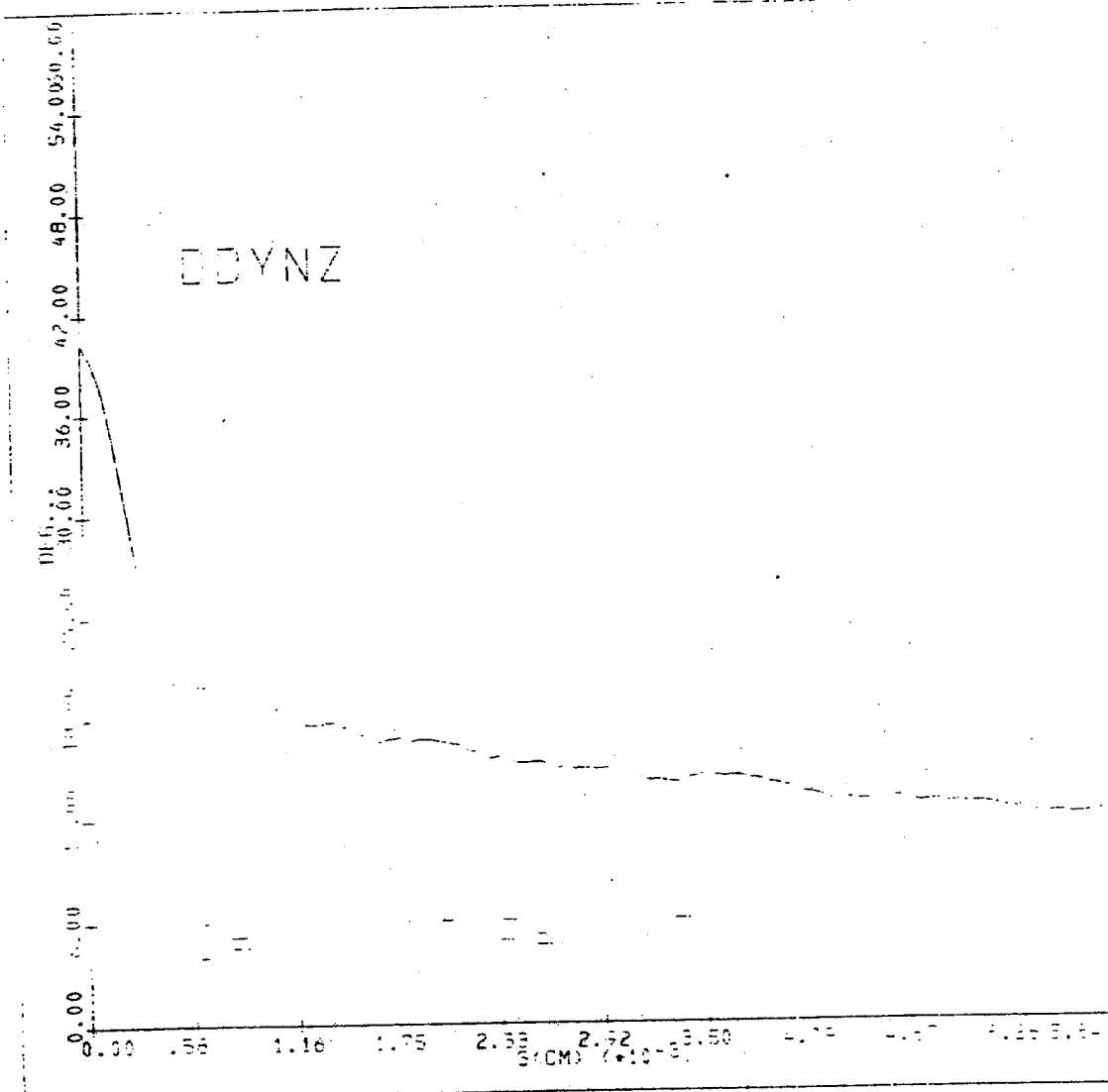
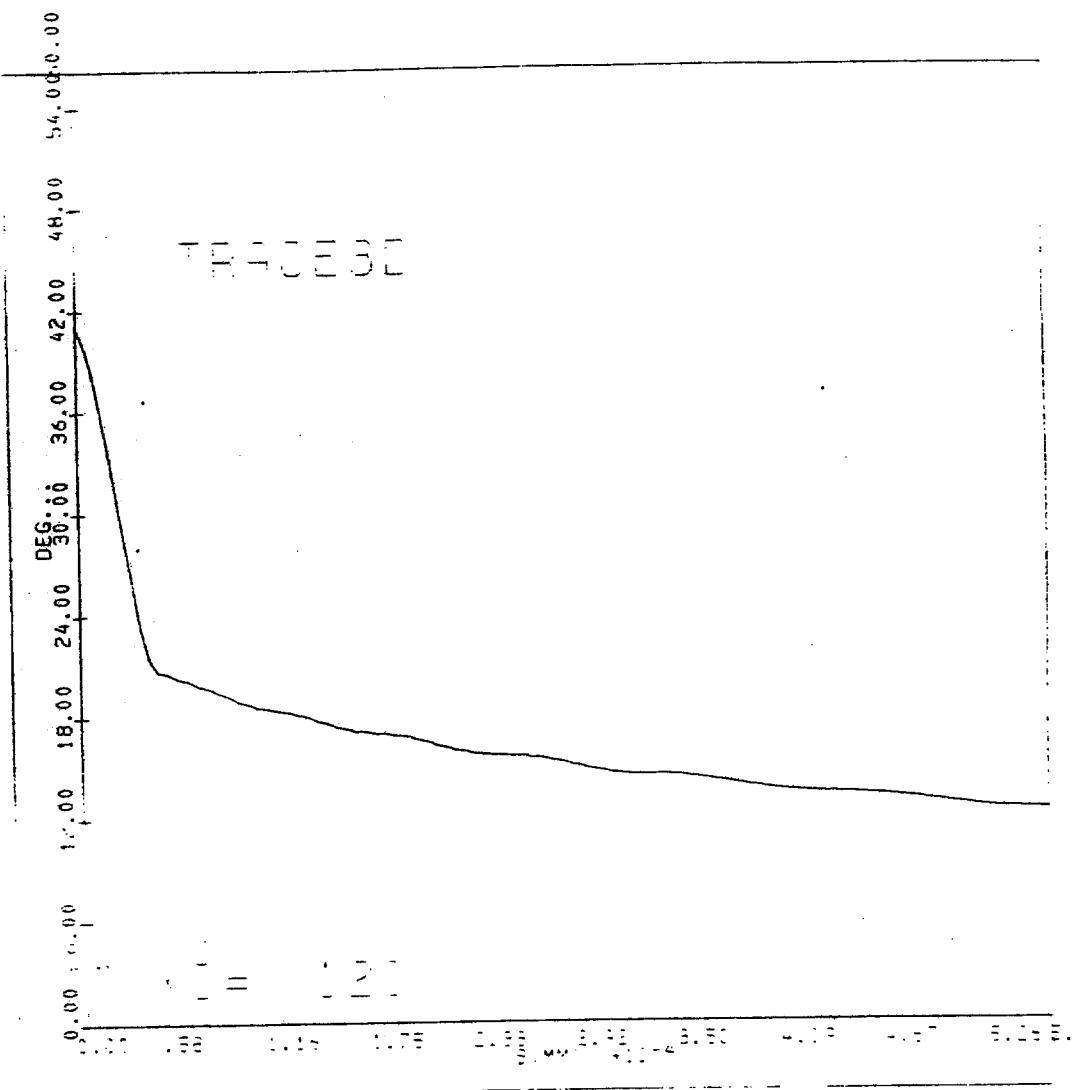


FIGURE # 9. beam at matched current  
 $I_b = 30 \text{ ma. beam}$



$$I_b = \frac{XI}{4}$$

FIGURE # 10(a)

z-plane matched for 33 ma.  
(1000 particles).  
(comp. to figure 10)

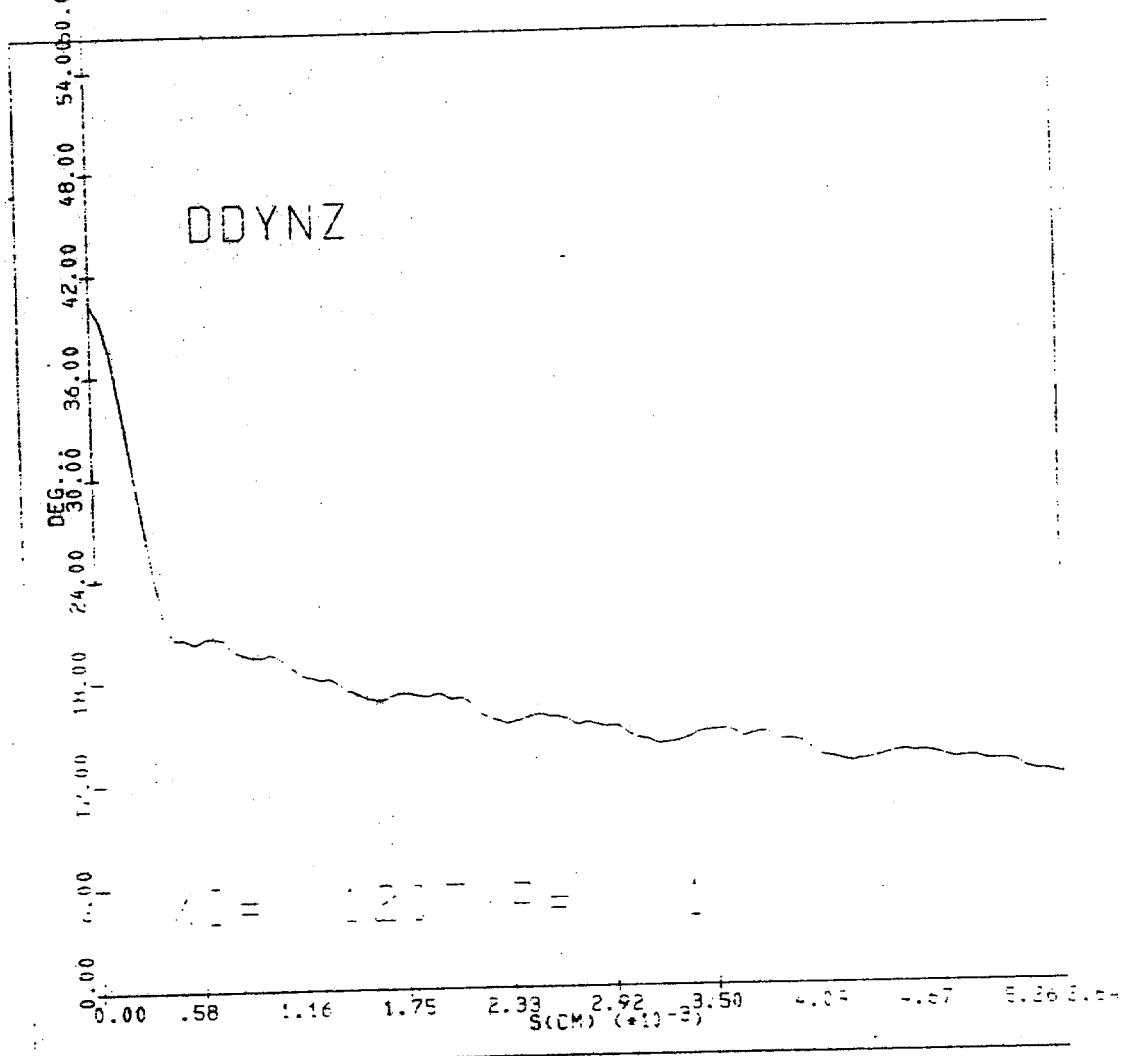


FIGURE #10(b)

z-plane matched for 30ma.

KV. distribution

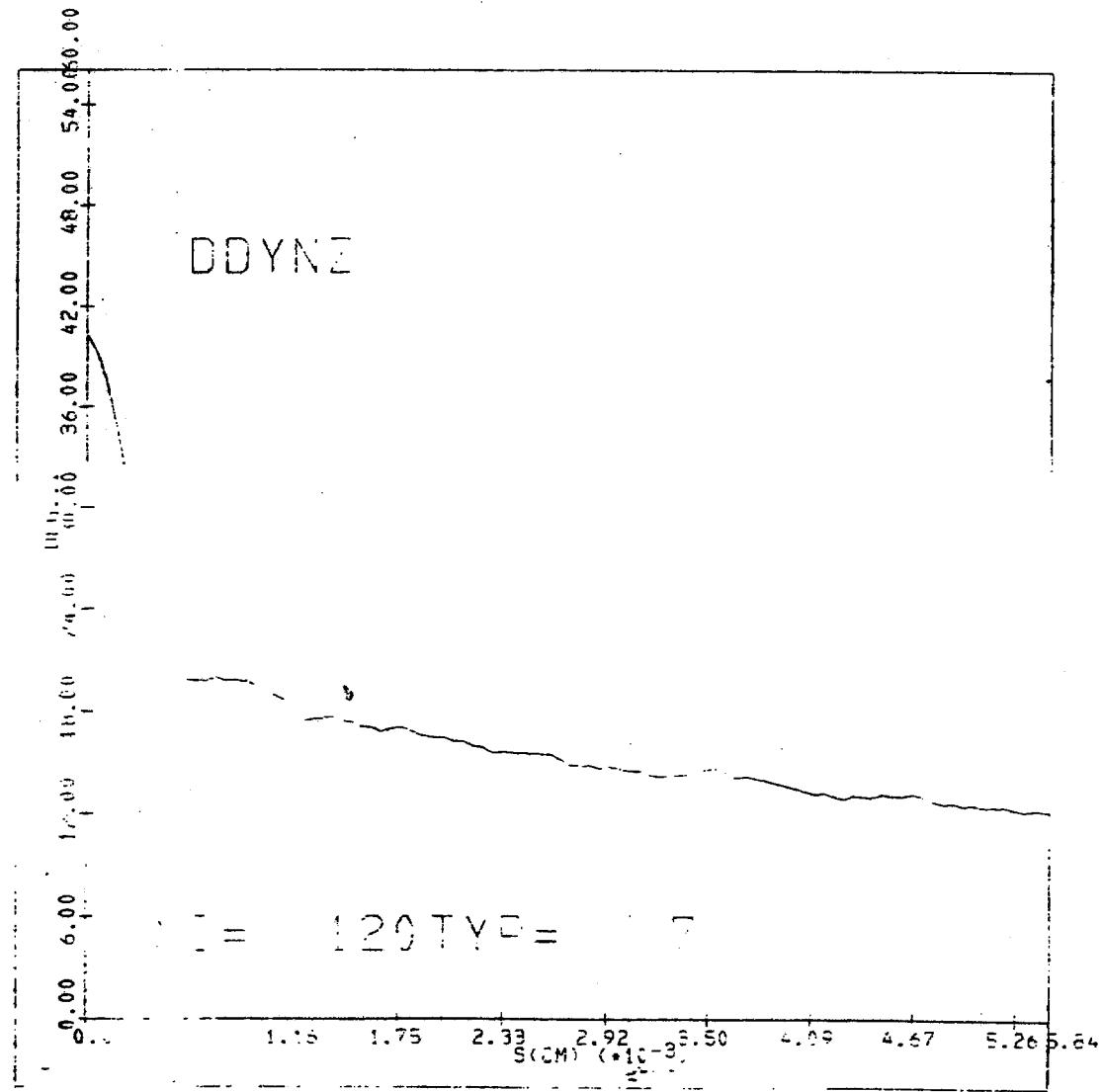
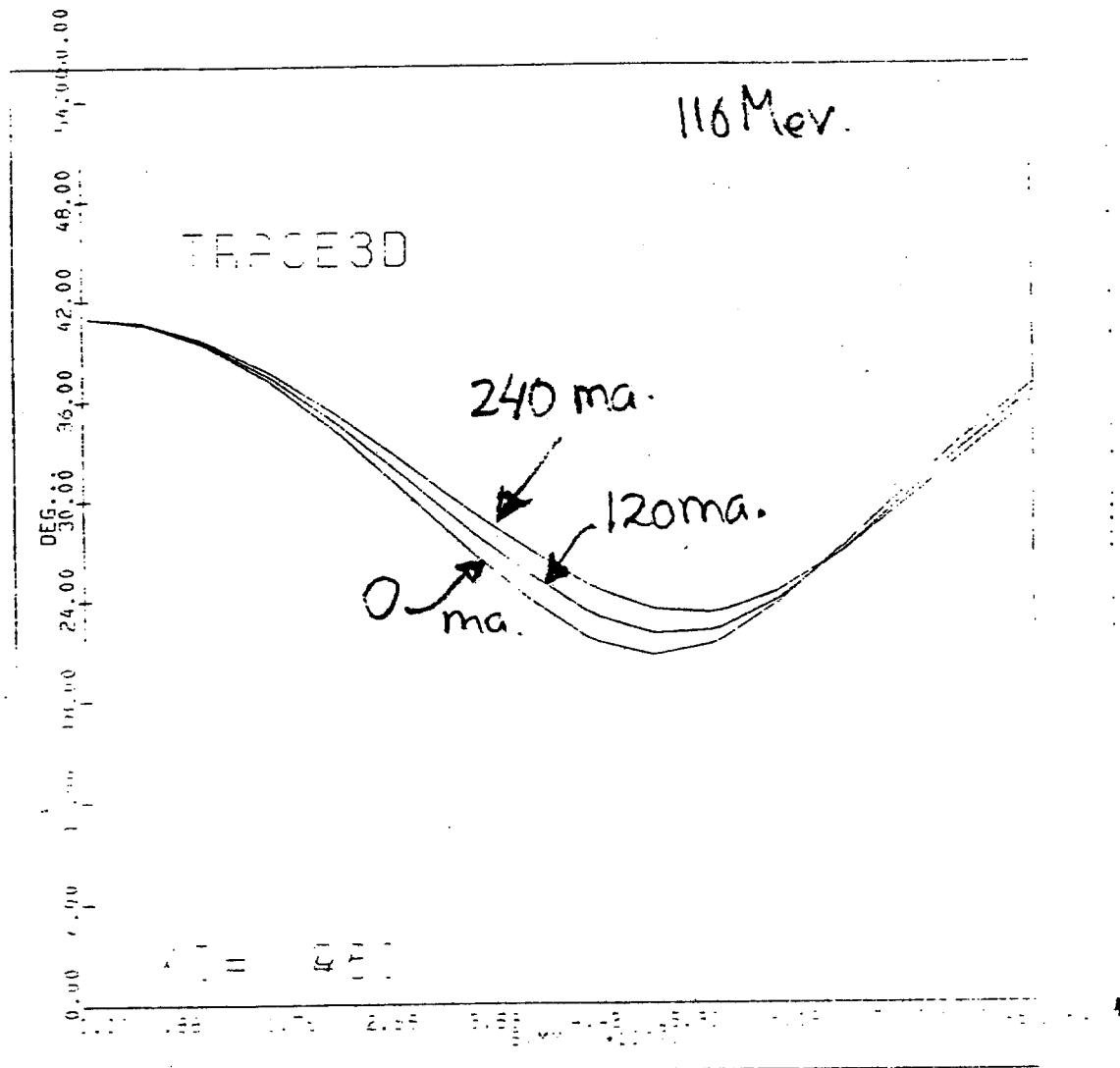


FIGURE # 11 space charge effects

on  $180^\circ$  bunch rotation.

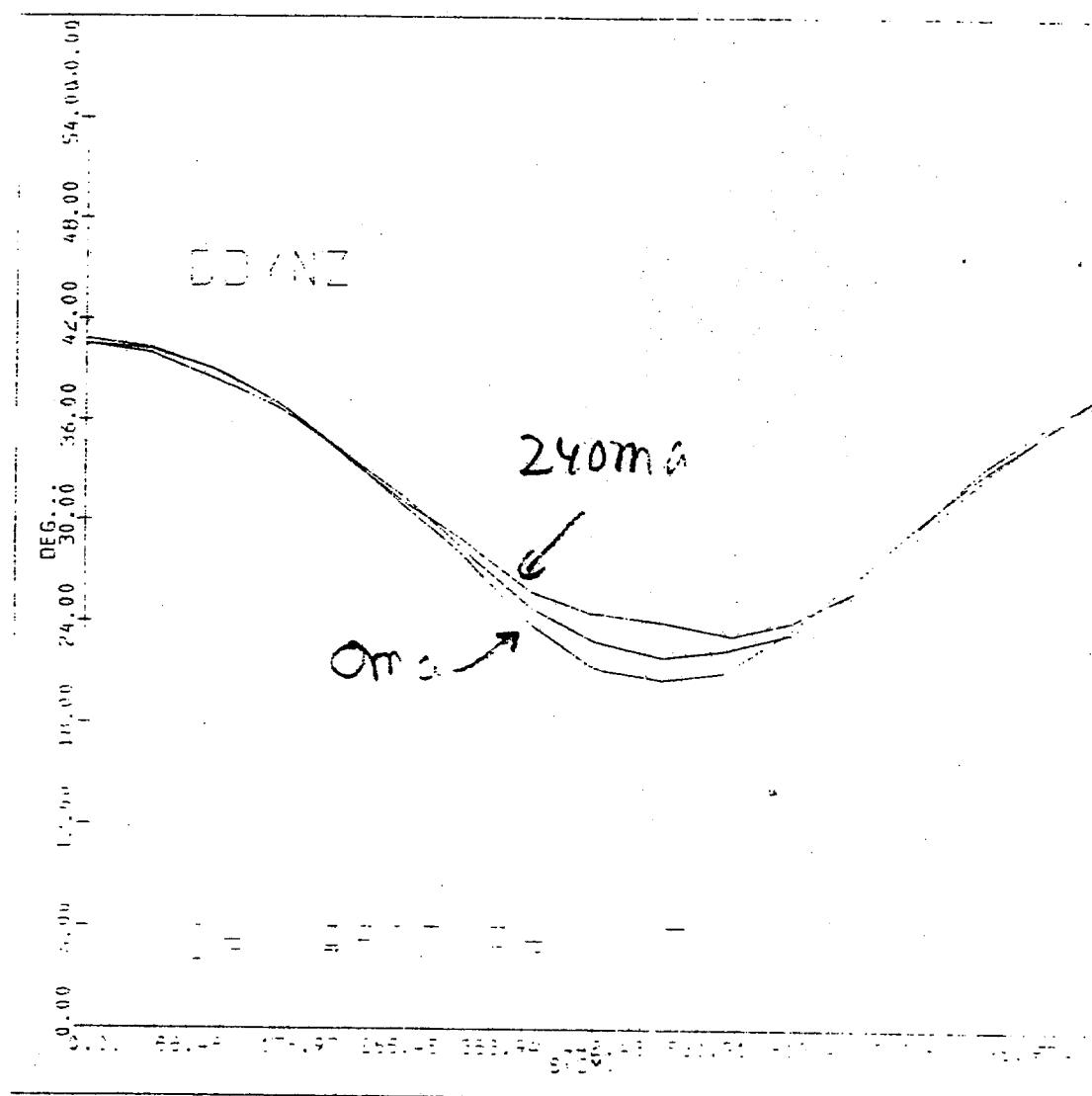
$I_b = 0, 120, 240 \text{ mA.}$



95 MHz bunch size trim a. 8-10 m  
(8.85 meter) bunch rotator ( $\Delta\theta \approx 178^\circ$ )  
[beam radius  $\langle \Delta r \rangle = 6 \text{ mm.}$ ]

FIGURE #12. bunch rotation  
study.

1000 particle simulation  
of 0, 120 and 240 mA  
beam.



(compare to figure #11.)

Figure # 13(a)

"O" Spec. charge bunch  
envelope after rotation

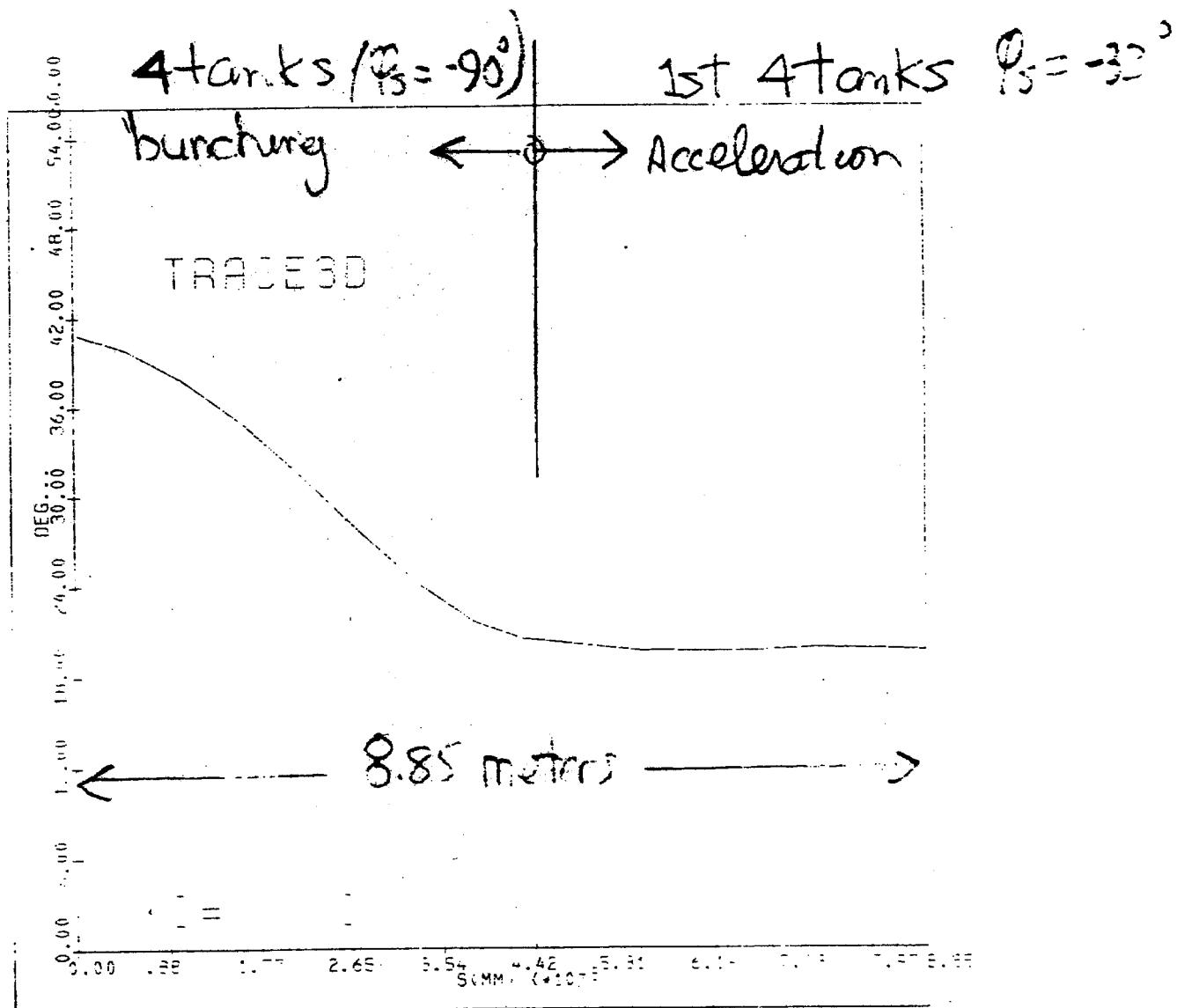


Figure # 13(b)

"O" space change bunch envelope.

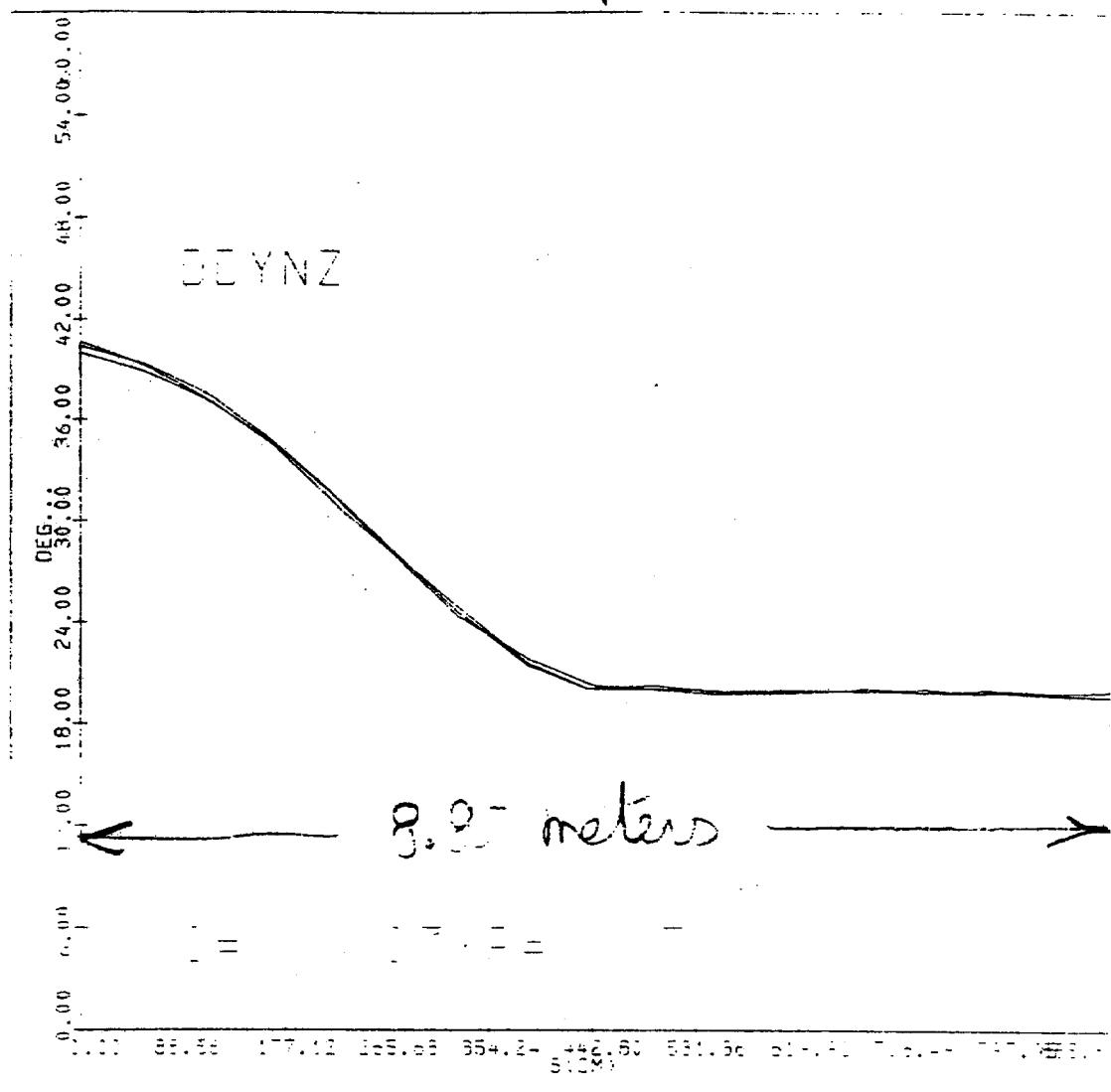
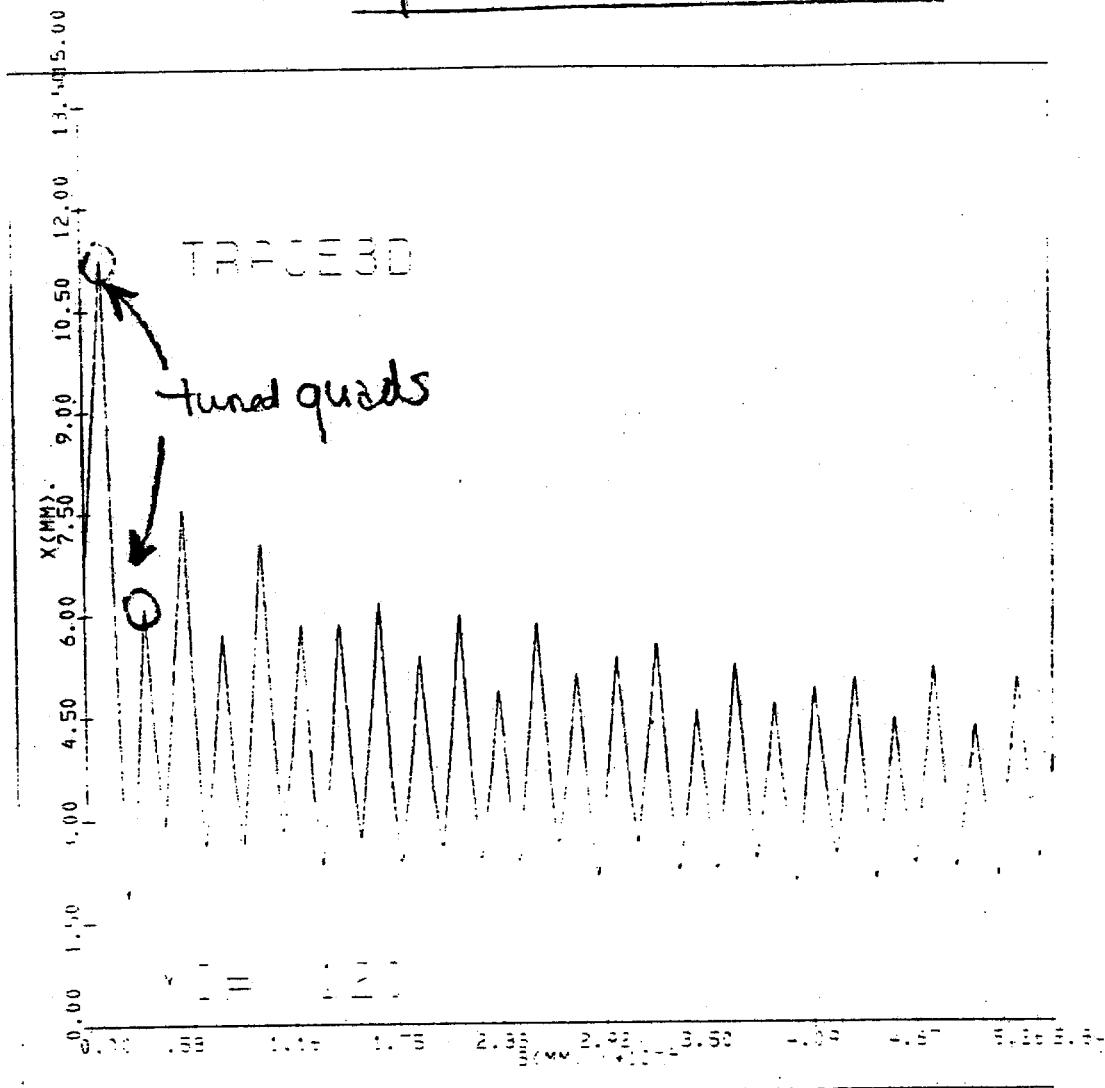


FIGURE #14

$\sim 80^\circ$  DV FODO

(2 quad TRACEx tune)



quad gradients from "DiskZ" +  
2-xplane quads tuned by TRACEx  
(no y-plane tuning)  $\rightarrow$  see figure 15

y plane trim

FIGURE # 15

-80° Δ) FODO  
(rough y-plane trim)

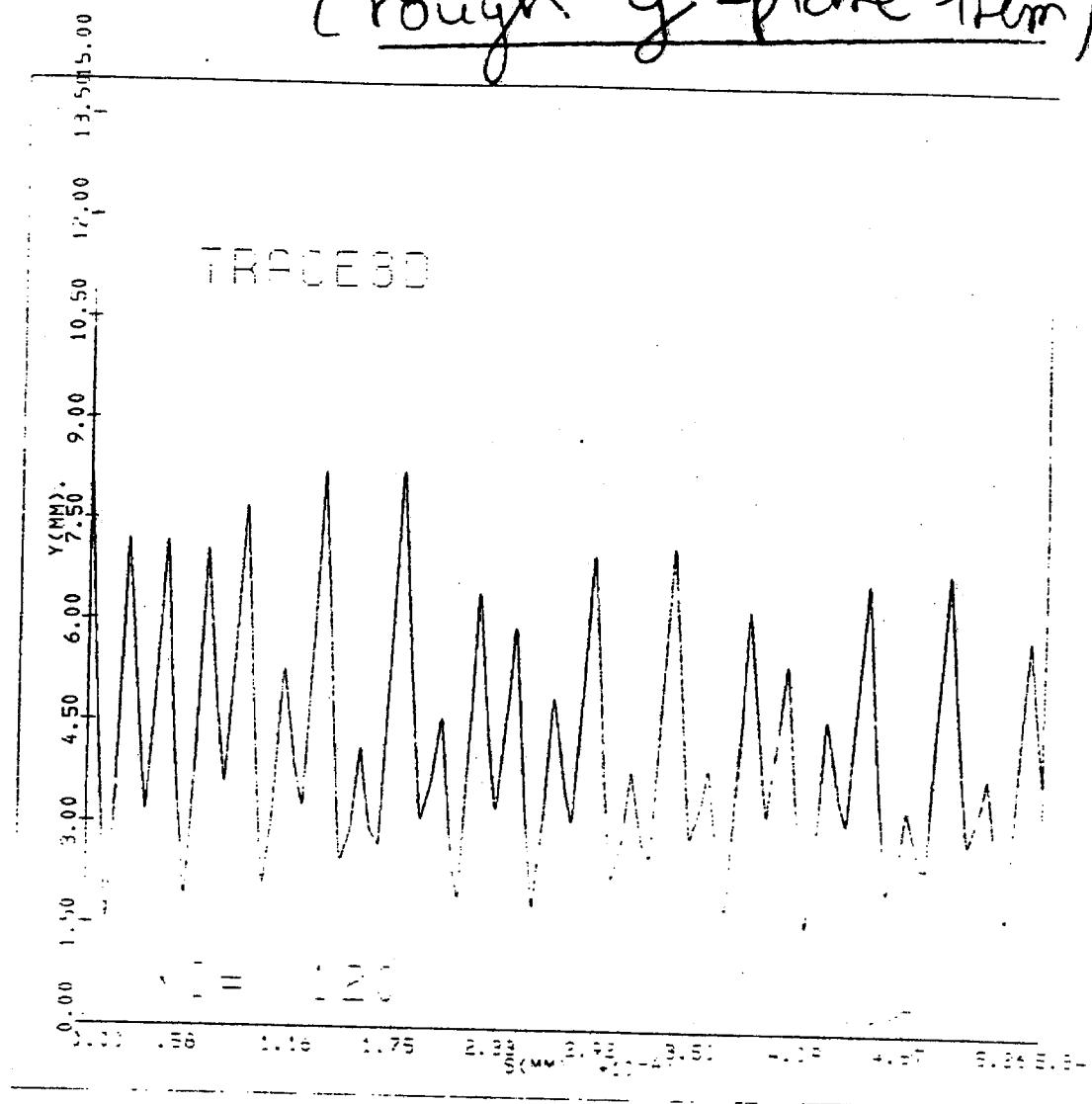


FIGURE #16.

(Some conditions as figure #14)

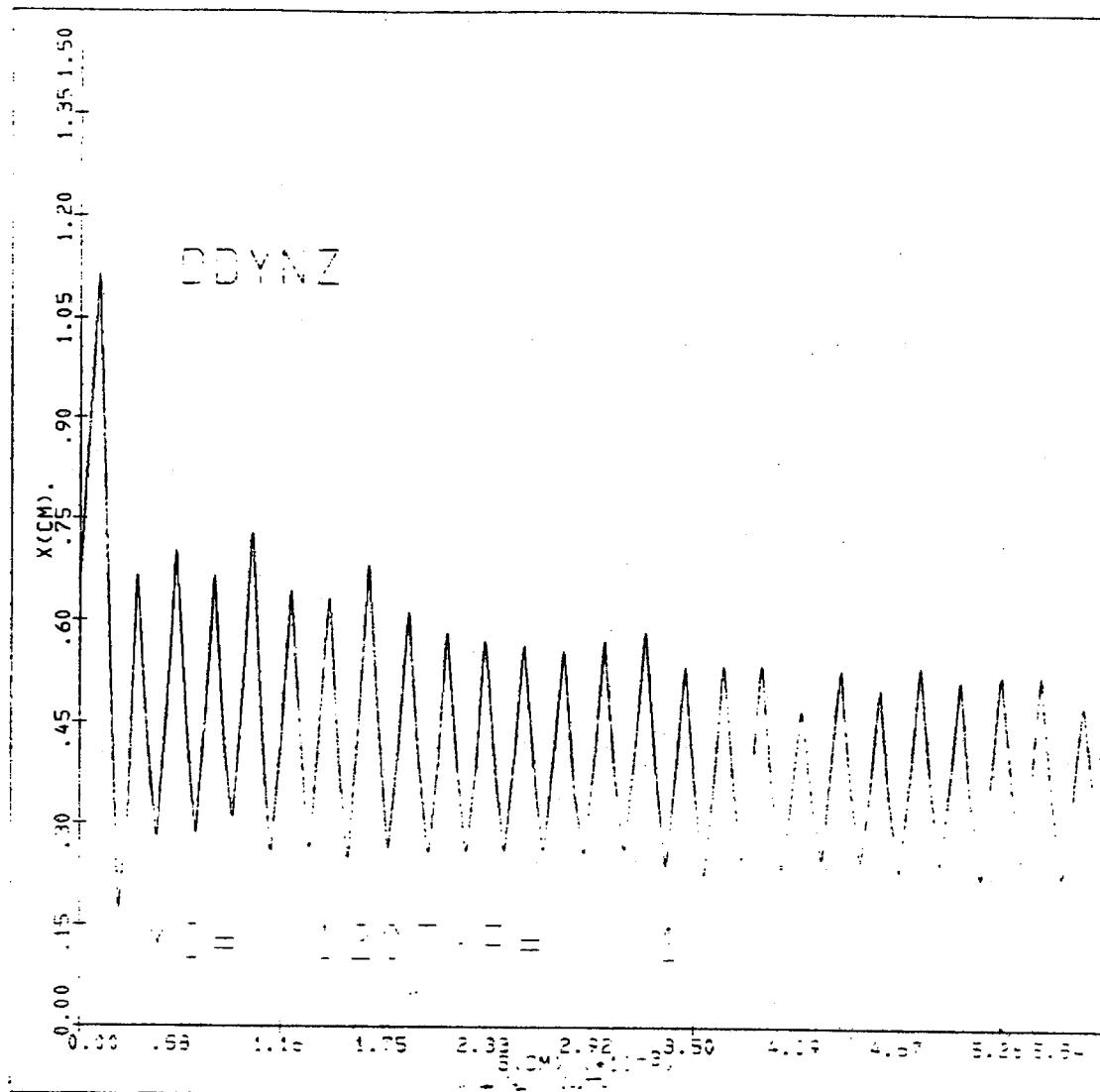


FIGURE # 17.

Same conditions as Figure 15.  
(rough g-plane trace).

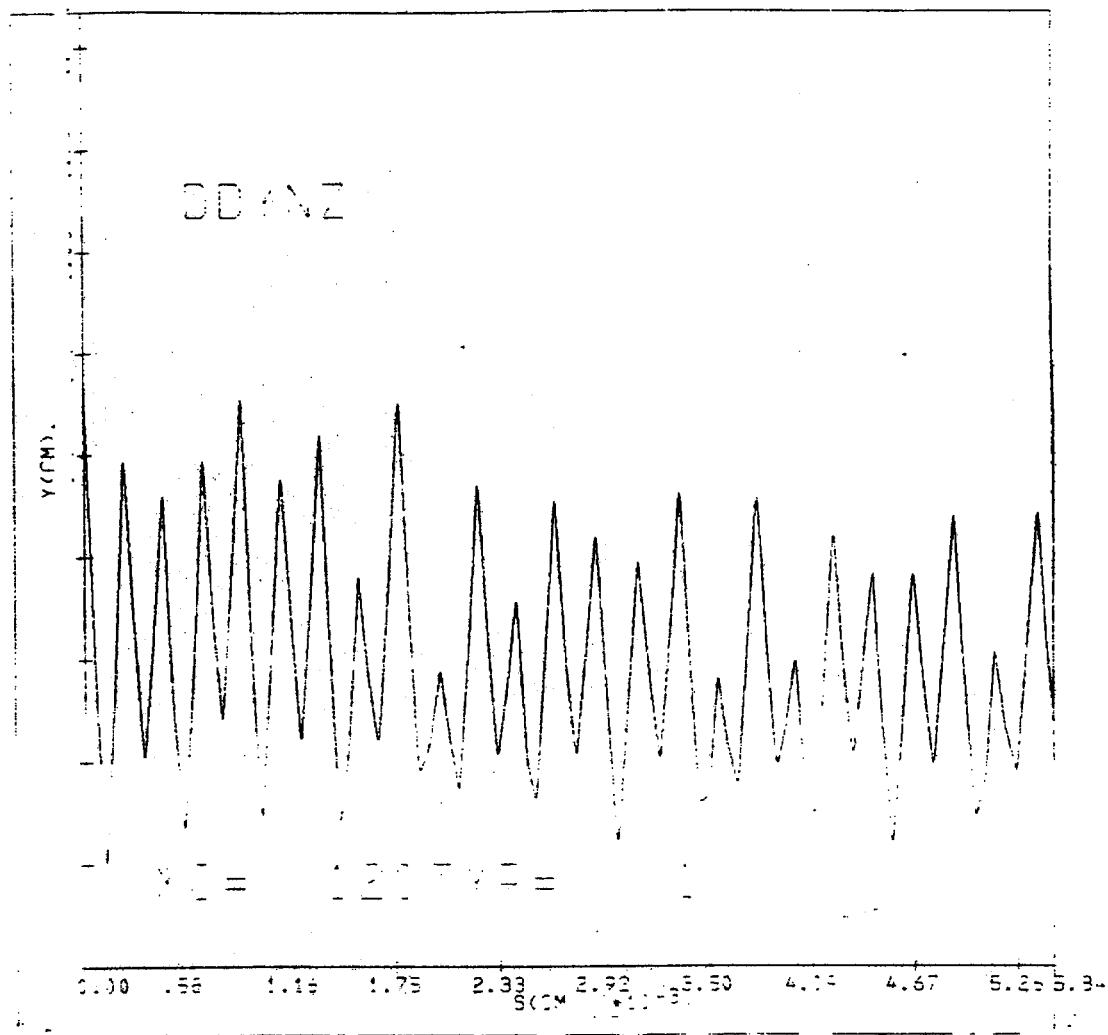
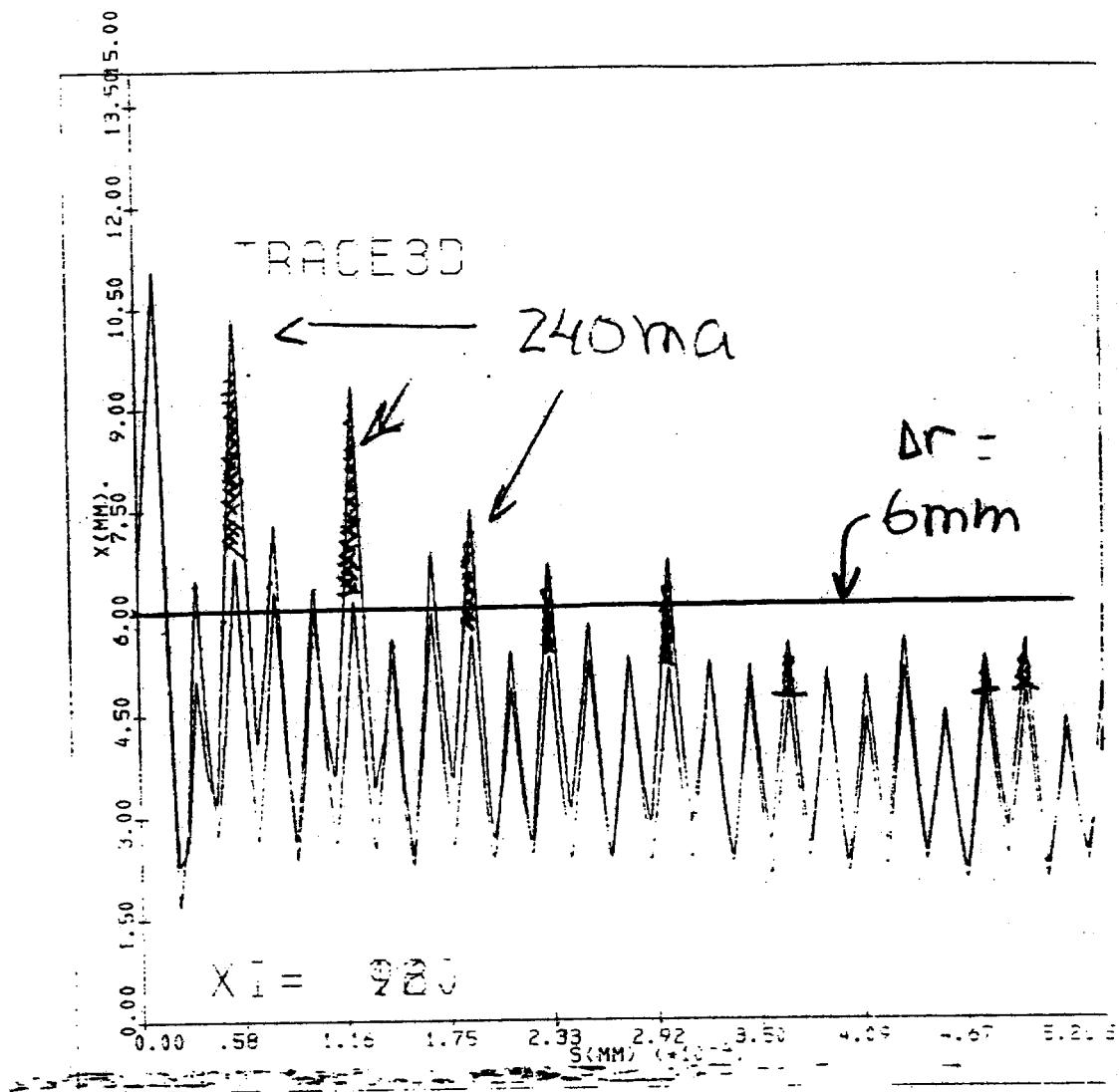


FIGURE #18. Shape-oscillations

Transverse space charge  
effects: 30 vs. 240 mA.

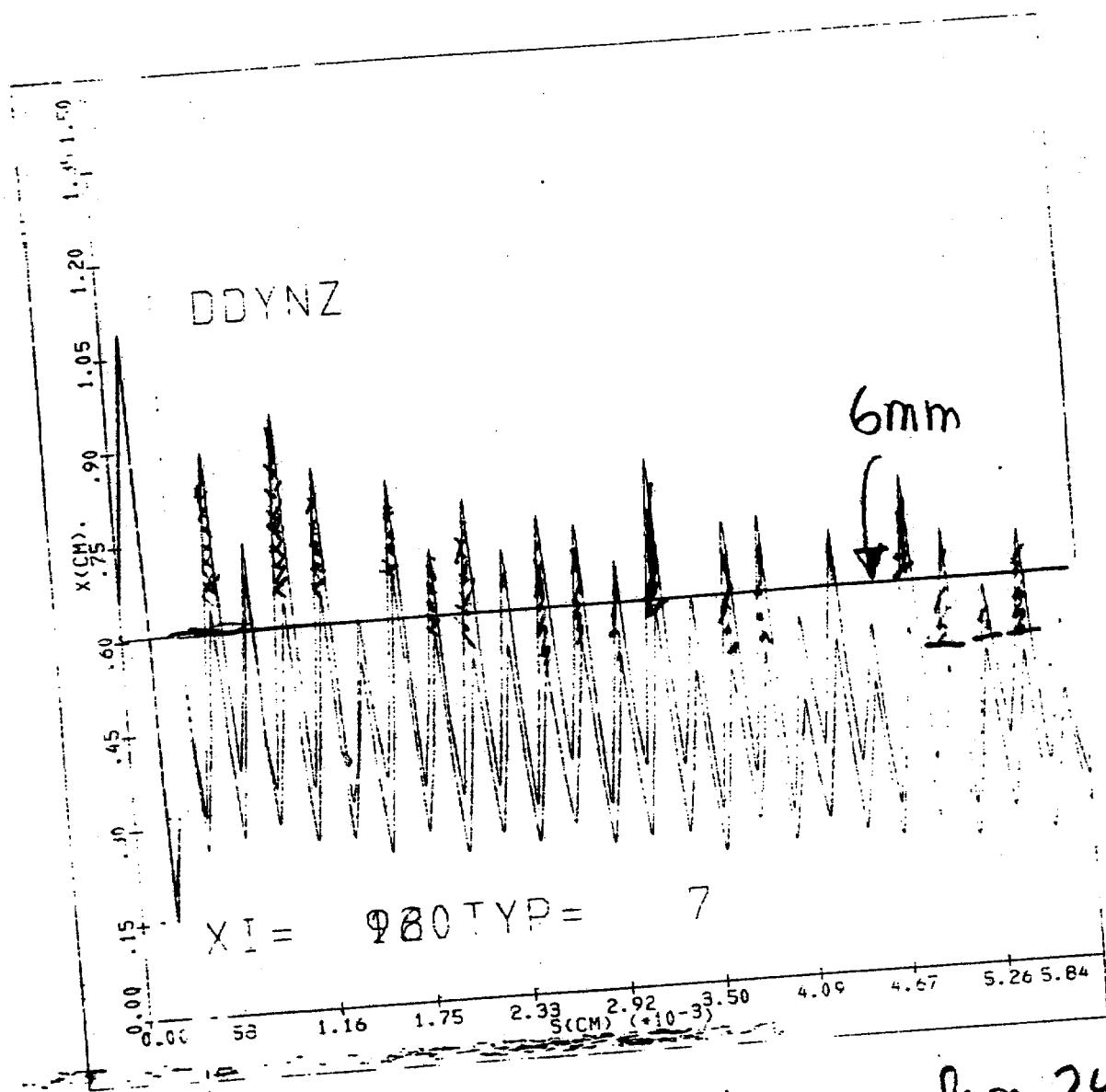


(240mA x-p.o.c. oscillations  
decay in 3-mm dynamics)  
(tune = 3) me not h).

Figure # 19. shape oscillations

30 ma vs 240 ma.

1000 particles



x-plane emittance blow-up from 240 ma beam.

Figure 20  $E_x (-63\%)$

RMS emittance blow-up

30 vs. 240 ma

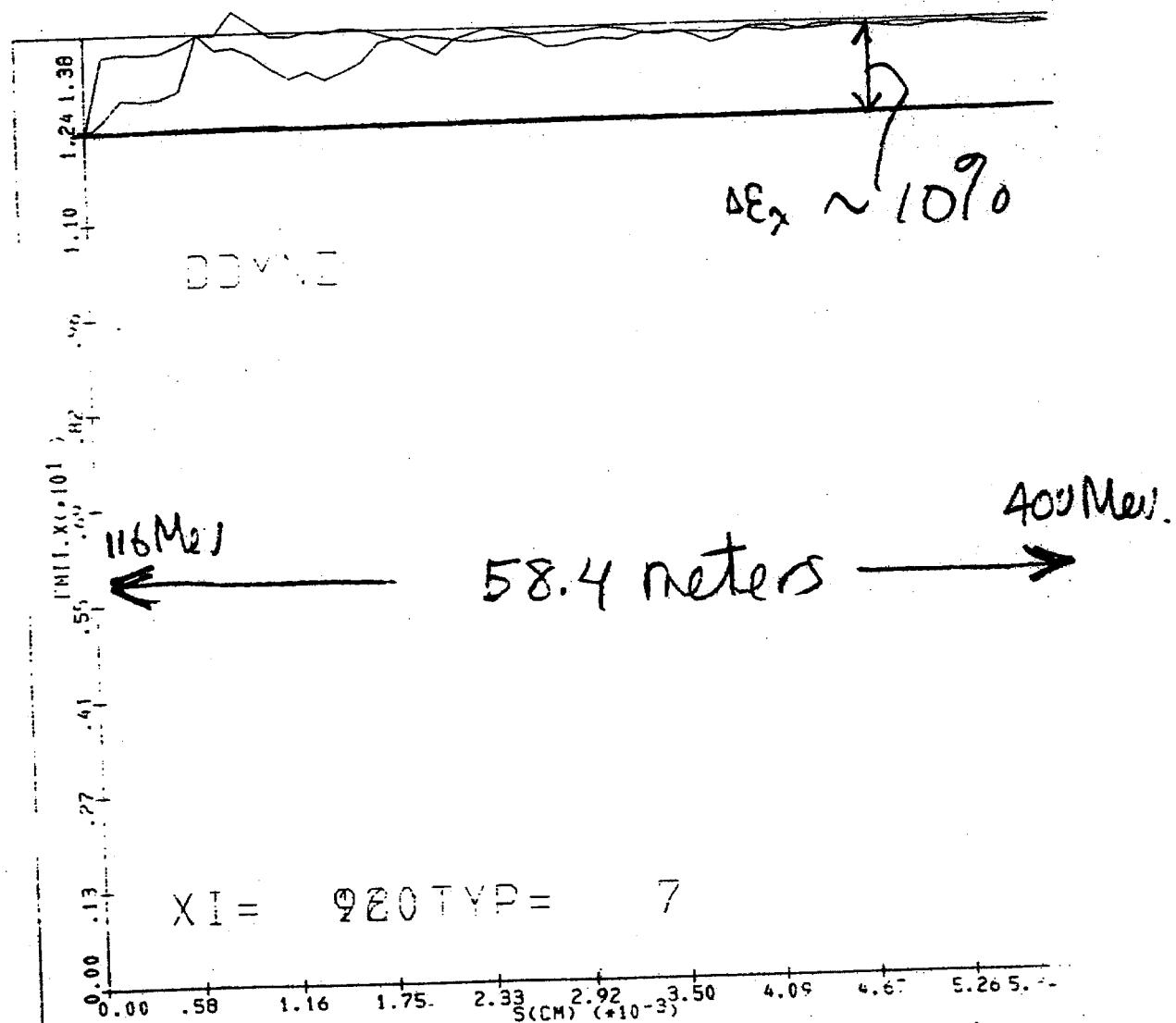


Figure #21.  $E_x(100\%)$

"100%" emittance blow-up

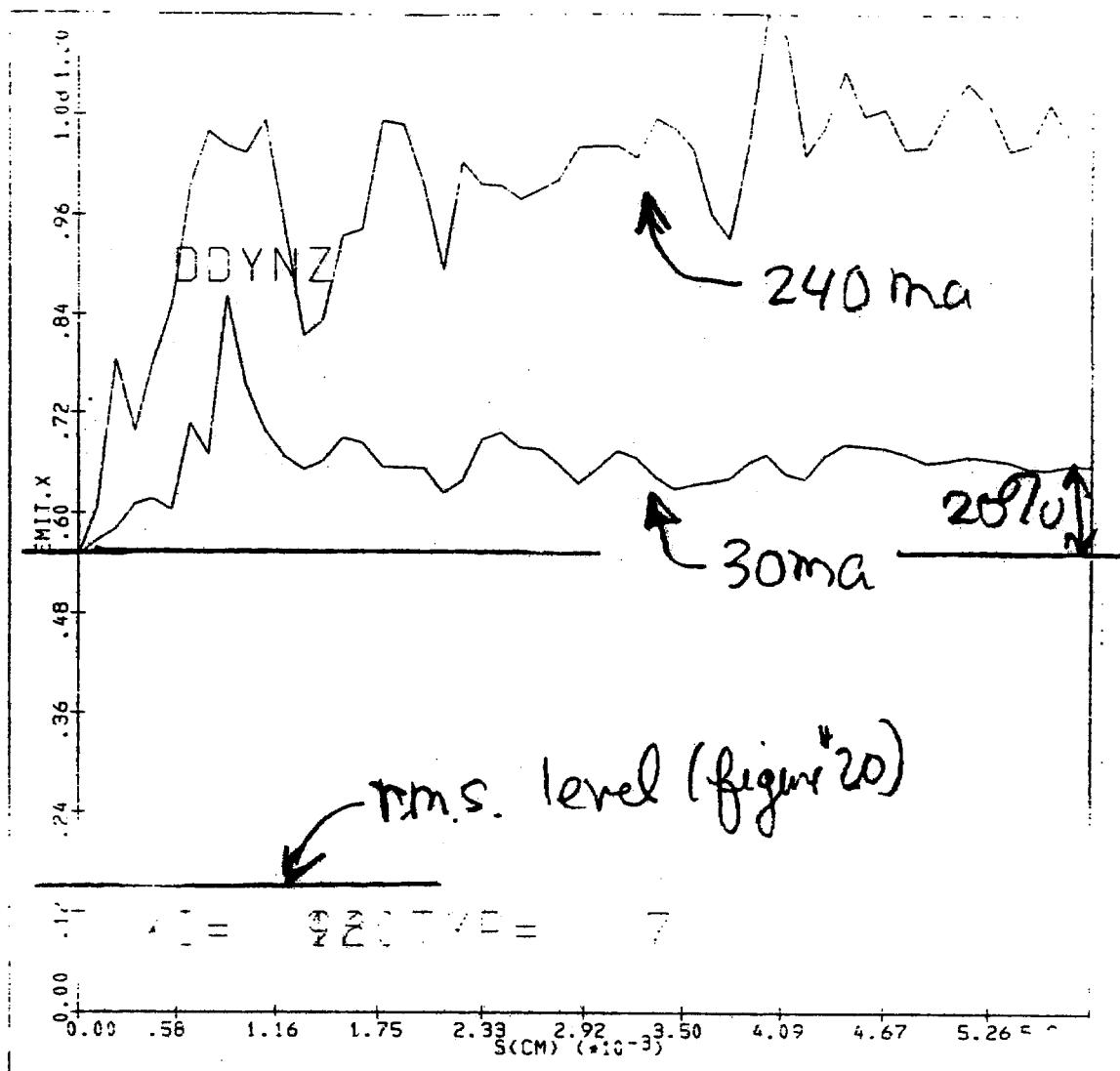
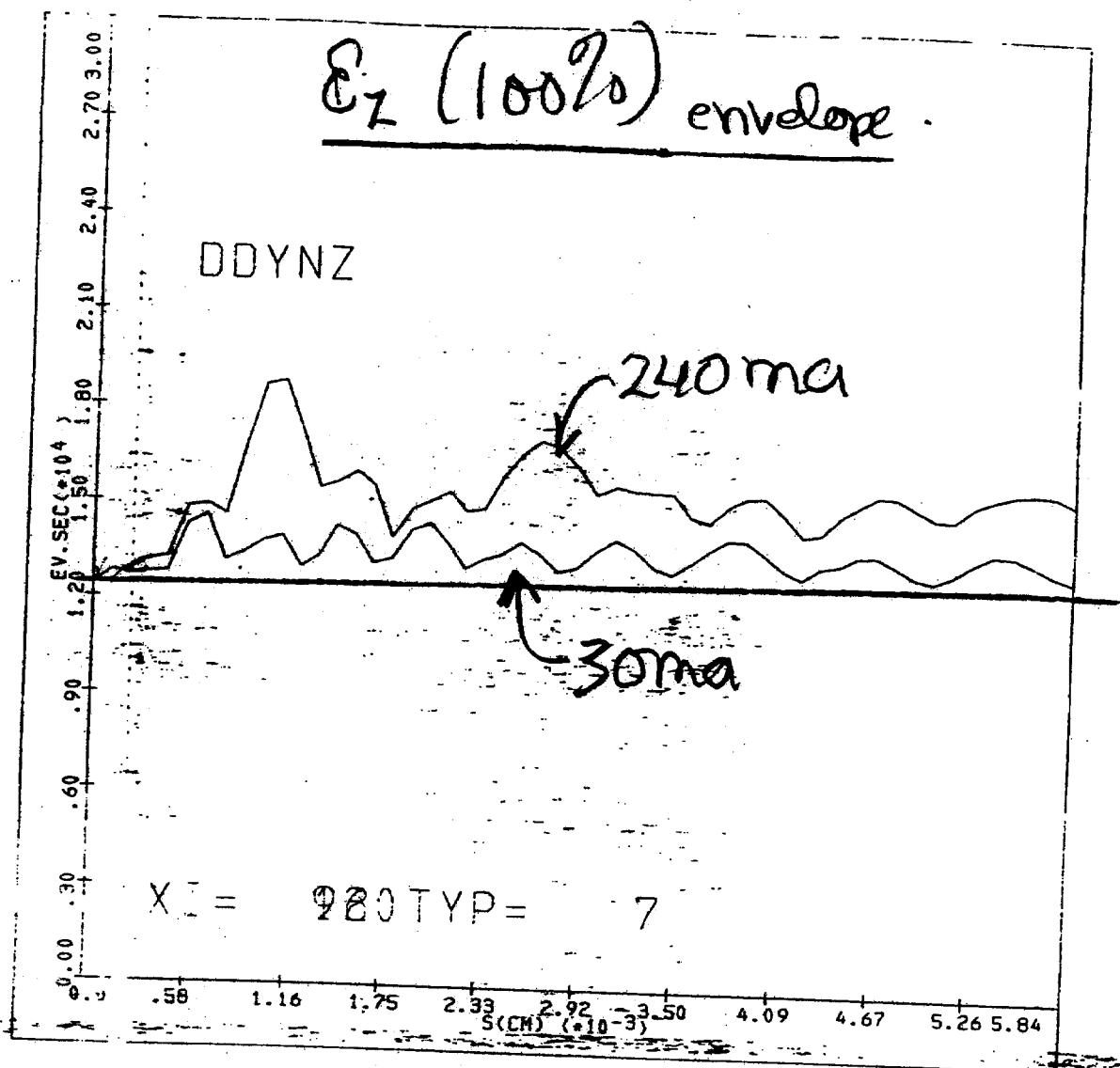


figure #2d. z-plane emittance  
blow-up of 30ma vs. 240ma.



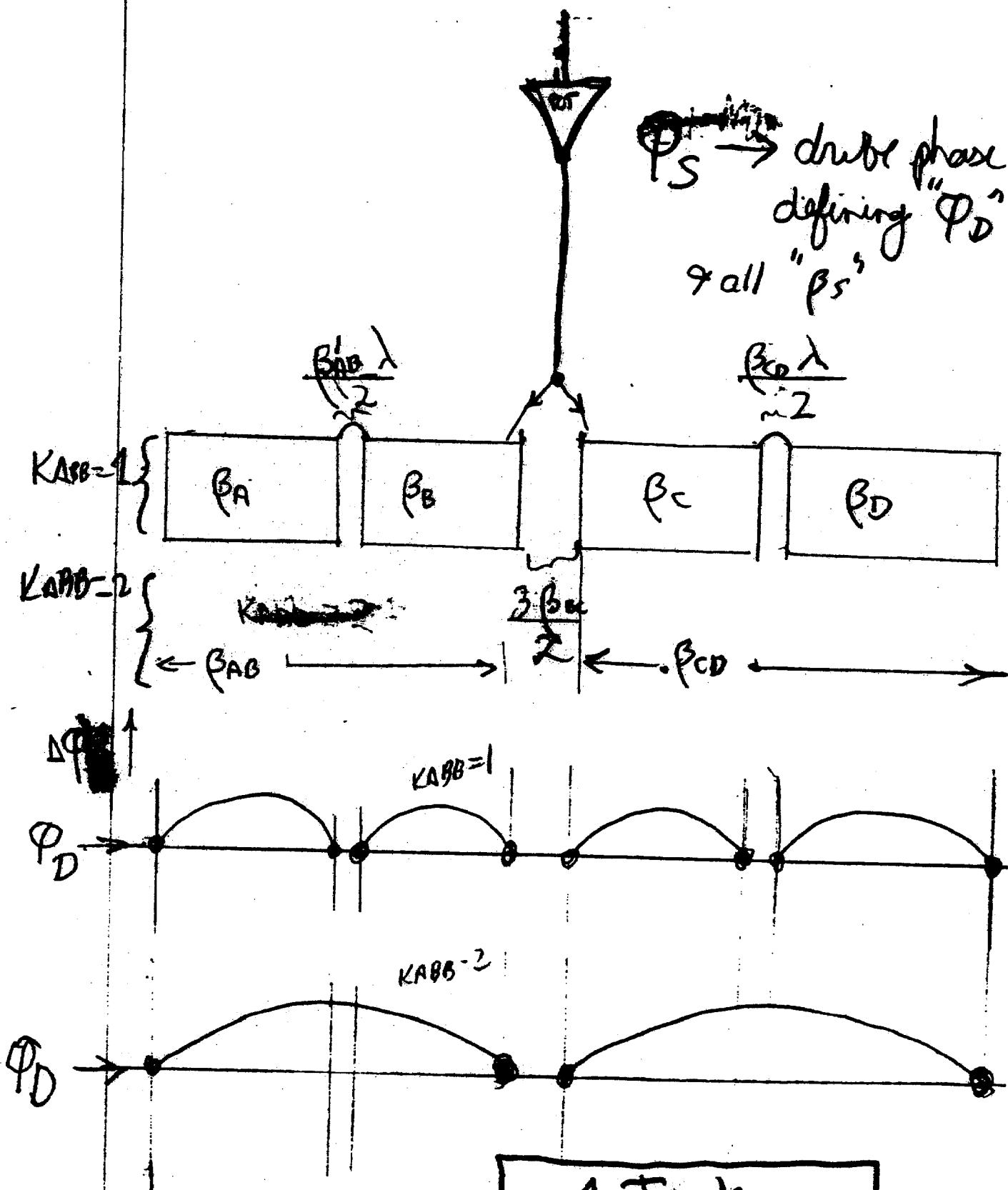


FIGURE 23.  
— Definition of  $\varphi_s$ ,  $\varphi_D$  &  $\Delta\varphi_D$  —

4 Tank  
Pressure Module

# I QUAD LATTICE $\rightarrow$ PDD TRANSVERSE LINEAR DYNAMICS HP 1.2. GRADIENTS SHOWN

$$\text{Ox}_2\text{Og} = 1 \cdot (\min \beta).$$

NT	XUMT	YUMT	BETAX	BETAY	HP1	HP2	GLA	GLB	CELL	NC
1	76. 769	76. 769	387. 284	83. 710	3. 023	2. 466	8. 000	8. 000	8. 507839	12
2	131. 024	131. 024	378. 481	26. 089	2. 466	3. 478	8. 000	8. 000	8. 507839	12
3	126. 548	126. 548	538. 877	29. 071	3. 478	3. 418	8. 000	8. 000	8. 507839	12
4	109. 661	109. 661	443. 042	42. 216	3. 418	3. 150	8. 000	8. 000	8. 507839	12
5	81. 414	81. 414	454. 688	70. 232	2. 928	3. 011	8. 000	8. 000	8. 602370	12
6	81. 747	81. 747	461. 738	71. 518	2. 935	3. 016	8. 000	8. 000	8. 789981	12
7	80. 354	80. 354	421. 506	70. 360	3. 091	3. 166	8. 000	8. 000	8. 963991	11
8	80. 315	80. 315	427. 194	71. 803	3. 098	3. 171	8. 000	8. 000	9. 127860	11
9	80. 644	80. 644	432. 761	73. 064	3. 104	3. 176	8. 000	8. 000	9. 288822	11
10	80. 742	80. 742	438. 207	74. 342	3. 110	3. 180	8. 000	8. 000	9. 446906	11
11	80. 814	80. 814	443. 532	75. 635	3. 117	3. 185	8. 000	8. 000	9. 602145	11
12	79. 778	79. 778	402. 112	73. 051	3. 321	3. 386	8. 000	8. 000	9. 747416	10
13	79. 748	79. 748	406. 434	74. 247	3. 327	3. 391	8. 000	8. 000	9. 883102	10
14	79. 702	79. 702	410. 673	75. 454	3. 333	3. 396	8. 000	8. 000	10. 016550	10
15	79. 641	79. 641	414. 831	76. 671	3. 339	3. 400	8. 000	8. 000	10. 147783	10
16	79. 565	79. 565	418. 909	77. 897	3. 345	3. 405	8. 000	8. 000	10. 276826	10
17	79. 476	79. 476	422. 910	79. 132	3. 351	3. 410	8. 000	8. 000	10. 403703	10
18	79. 375	79. 375	426. 834	80. 376	3. 357	3. 415	8. 000	8. 000	10. 528445	10
19	79. 685	79. 685	384. 287	74. 343	3. 659	3. 716	8. 000	8. 000	10. 644824	9
20	79. 528	79. 528	387. 450	75. 432	3. 665	3. 720	8. 000	8. 000	10. 753151	9
21	79. 363	79. 363	390. 560	76. 327	3. 670	3. 725	8. 000	8. 000	10. 859826	9
22	79. 193	79. 193	393. 629	77. 628	3. 676	3. 730	8. 000	8. 000	10. 964869	9
23	79. 016	79. 016	396. 629	78. 734	3. 682	3. 735	8. 000	8. 000	11. 068300	9
24	78. 834	78. 834	399. 591	79. 946	3. 687	3. 740	8. 000	8. 000	11. 170137	9
25	78. 647	78. 647	402. 506	80. 963	3. 693	3. 745	8. 000	8. 000	11. 270402	9
26	78. 455	78. 455	403. 375	82. 084	3. 699	3. 750	8. 000	8. 000	11. 369113	9
27	78. 241	78. 241	408. 266	83. 235	3. 705	3. 755	8. 000	8. 000	11. 446284	9
28	78. 041	78. 041	411. 043	84. 364	3. 710	3. 760	8. 000	8. 000	11. 361871	9
29	79. 303	79. 303	413. 762	82. 568	3. 745	3. 815	8. 000	8. 000	11. 655969	9
30	79. 084	79. 084	416. 425	83. 988	3. 771	3. 820	8. 000	8. 000	11. 748460	9
31	78. 047	78. 047	371. 900	78. 594	4. 123	4. 170	8. 000	8. 000	11. 834674	8
32	77. 824	77. 824	374. 037	79. 350	4. 128	4. 175	8. 000	8. 000	11. 914440	8
33	77. 600	77. 600	376. 147	80. 508	4. 133	4. 180	8. 000	8. 000	11. 993099	8
34	78. 622	78. 622	378. 206	79. 314	4. 188	4. 234	8. 000	8. 000	12. 070663	8
35	78. 386	78. 386	380. 239	80. 265	4. 193	4. 239	8. 000	8. 000	12. 147147	8
36	78. 149	78. 149	382. 246	81. 219	4. 198	4. 244	8. 000	8. 000	12. 222365	8
37	77. 911	77. 911	384. 230	82. 175	4. 204	4. 249	8. 000	8. 000	12. 294930	8
38	77. 673	77. 673	386. 190	83. 134	4. 209	4. 254	8. 000	8. 000	12. 370236	8
39	78. 645	78. 645	388. 123	81. 929	4. 264	4. 308	8. 000	8. 000	12. 442356	8
40	78. 397	78. 397	390. 011	82. 880	4. 269	4. 313	8. 000	8. 000	12. 513844	8
41	78. 148	78. 148	391. 875	83. 833	4. 275	4. 319	8. 000	8. 000	12. 584134	8
42	77. 899	77. 899	393. 717	84. 788	4. 280	4. 324	8. 000	8. 000	12. 653439	8
43	77. 650	77. 650	395. 539	85. 745	4. 286	4. 329	8. 000	8. 000	12. 721771	8
44	77. 401	77. 401	397. 341	86. 705	4. 291	4. 334	8. 000	8. 000	12. 789146	8
45	78. 320	78. 320	399. 101	85. 480	4. 346	4. 389	8. 000	8. 000	12. 835575	8
46	78. 062	78. 062	400. 833	86. 431	4. 352	4. 394	8. 000	8. 000	12. 921071	8
47	77. 805	77. 805	402. 547	87. 384	4. 357	4. 399	8. 000	8. 000	12. 985649	8
48	77. 548	77. 548	404. 243	88. 338	4. 363	4. 405	8. 000	8. 000	13. 049320	8
49	77. 291	77. 291	405. 921	89. 294	4. 369	4. 410	8. 000	8. 000	13. 112097	8
50	78. 170	78. 170	407. 557	88. 060	4. 423	4. 465	8. 000	8. 000	13. 173994	8
51	77. 906	77. 906	409. 170	89. 008	4. 429	4. 470	8. 000	8. 000	13. 235022	8
52	77. 643	77. 643	410. 767	89. 958	4. 435	4. 476	8. 000	8. 000	13. 295194	8

SYSTEM SUMMARY

### LINÉAR LONG PARAMS=>

NT MUL GAML BETAL  
1 19.975 .042 24.081

2 39.975 .042 24.081

NT	XMUT	YMUT	BETAX	BETAY	HP1	HP2	GLA	GLB	CELL	NC
1	76.769	76.769	387.284	63.710	3.023	2.466	8.000	8.000	8.507839	12
2	131.024	131.024	578.481	26.085	2.464	3.478	8.000	8.000	8.507839	12
3	126.548	126.548	538.877	29.071	3.478	3.418	8.000	8.000	8.507839	12
4	109.661	109.661	443.042	42.216	3.418	3.150	8.000	8.000	8.507839	12
5	44.995	45.012	577.313	162.712	2.250	2.309	8.000	8.000	8.602370	12
6	45.019	45.008	577.154	162.718	2.240	2.297	8.000	8.000	8.788981	12
7	44.989	45.001	533.054	163.045	2.323	2.376	8.000	8.000	8.963991	11
8	45.006	45.000	534.244	163.366	2.316	2.367	8.000	8.000	9.127860	11
9	45.010	45.020	535.777	164.268	2.309	2.359	8.000	8.000	9.268822	11
10	44.997	44.984	355.319	175.858	2.302	2.351	8.000	8.000	9.446706	11
11	44.992	45.001	556.614	176.337	2.296	2.344	8.000	8.000	9.602145	11
12	44.995	44.992	500.985	168.164	2.404	2.449	8.000	8.000	9.747414	10
13	44.998	45.004	503.252	169.240	2.401	2.445	8.000	8.000	9.883102	10
14	45.006	45.003	505.622	170.372	2.398	2.441	8.000	8.000	10.016350	10
15	45.008	45.014	508.076	171.553	2.396	2.438	8.000	8.000	10.147783	10
16	45.016	45.011	510.601	172.778	2.394	2.435	8.000	8.000	10.276826	10
17	44.988	44.993	526.023	183.157	2.392	2.432	8.000	8.000	10.403703	10
18	44.994	44.993	528.364	184.374	2.390	2.430	8.000	8.000	10.528445	10
19	44.998	45.001	470.446	171.193	2.337	2.375	8.000	8.000	10.644824	9
20	45.002	45.000	473.041	172.525	2.538	2.575	8.000	8.000	10.753151	9
21	45.002	45.005	475.646	173.873	2.539	2.576	8.000	8.000	10.859826	9
22	45.006	45.004	478.258	175.236	2.540	2.576	8.000	8.000	10.964869	9
23	45.006	45.009	480.872	176.612	2.542	2.578	8.000	8.000	11.068300	9
24	45.010	45.007	483.488	178.000	2.544	2.579	8.000	8.000	11.170137	9
25	45.010	45.012	486.102	179.400	2.546	2.581	8.000	8.000	11.270402	9
26	45.013	45.010	488.712	180.809	2.549	2.583	8.000	8.000	11.349113	9
27	44.988	44.991	500.910	189.949	2.552	2.586	8.000	8.000	11.464284	9
28	44.991	44.991	503.399	191.350	2.555	2.588	8.000	8.000	11.561671	9
29	44.991	44.994	505.886	192.761	2.558	2.591	8.000	8.000	11.639949	9
30	44.993	44.993	508.369	194.180	2.562	2.594	8.000	8.000	11.748600	9
31	44.992	44.994	451.767	178.805	2.769	2.800	8.000	8.000	11.834574	8
32	44.992	44.993	454.088	180.140	2.774	2.805	8.000	8.000	11.914440	8
33	44.992	44.994	456.397	181.478	2.779	2.809	8.000	8.000	11.993099	8
34	44.993	44.993	458.694	182.817	2.784	2.814	8.000	8.000	12.070443	8
35	44.992	44.994	460.978	184.158	2.790	2.820	8.000	8.000	12.147147	8
36	44.992	44.993	463.249	185.500	2.795	2.825	8.000	8.000	12.222565	8
37	44.992	44.994	465.509	186.843	2.801	2.831	8.000	8.000	12.294730	8
38	44.992	44.992	467.754	188.188	2.807	2.836	8.000	8.000	12.370256	8
39	44.991	44.993	469.986	189.533	2.813	2.842	8.000	8.000	12.442556	8
40	44.992	44.992	472.205	190.878	2.819	2.848	8.000	8.000	12.513844	8
41	44.991	44.993	474.412	192.224	2.826	2.854	8.000	8.000	12.584134	8
42	45.010	45.008	470.027	187.471	2.833	2.862	8.000	8.000	12.653439	8
43	45.008	45.009	472.221	188.811	2.840	2.868	8.000	8.000	12.721771	8
44	45.008	45.007	474.401	190.150	2.847	2.875	8.000	8.000	12.789146	8
45	45.007	45.008	476.568	191.489	2.854	2.882	8.000	8.000	12.855575	8
46	45.007	45.006	478.719	192.827	2.861	2.889	8.000	8.000	12.921071	8
47	45.006	45.006	480.856	194.165	2.869	2.896	8.000	8.000	12.983649	8
48	45.006	45.005	482.979	195.501	2.876	2.903	8.000	8.000	13.049320	8
49	45.004	45.005	485.087	196.836	2.884	2.910	8.000	8.000	13.112097	8
50	45.004	45.003	487.183	198.170	2.891	2.918	8.000	8.000	13.173994	8
51	45.003	45.003	489.263	199.503	2.899	2.926	8.000	8.000	13.235022	8
52	45.002	45.002	491.329	200.834	2.907	2.933	8.000	8.000	13.295194	8

SYSTEM SUMMARY----->>

LINEAR LONG. PARAMS-->

NT	MUL	GAML	BETA1
1	19.975	.042	24.081
2	19.975	.042	24.081
14	3.40	UCLP, GO, T811.	0.118KLNS.

\*\* END OF LISTING \*\*

NT	XNUT	YNUT	BETAX	BETAY	HP1	HP2	GLA	GLB	CELL	NC
1	76. 769	76. 769	387. 284	83. 710	3. 023	2. 466	8. 000	8. 000	8. 507839	12
2	131. 024	131. 024	578. 481	26. 085	2. 466	3. 478	8. 000	8. 000	8. 507839	12
3	126. 348	126. 348	538. 877	29. 071	3. 478	3. 418	8. 000	8. 000	8. 507839	12
4	109. 661	109. 661	443. 042	42. 216	3. 418	3. 130	8. 000	8. 000	8. 507839	12
5	83. 036	83. 036	454. 854	67. 965	3. 150	3. 000	8. 000	8. 000	8. 402370	12
6	83. 048	83. 048	461. 922	69. 638	3. 000	3. 000	8. 000	8. 000	8. 788491	12
7	74. 468	74. 468	424. 036	79. 740	3. 000	3. 000	8. 000	8. 000	8. 763991	11
8	74. 453	74. 453	429. 703	81. 454	3. 000	3. 000	8. 000	8. 000	9. 127860	11
9	74. 407	74. 407	435. 263	83. 200	3. 000	3. 000	8. 000	8. 000	9. 288822	11
10	74. 331	74. 331	440. 726	84. 978	3. 000	3. 000	8. 000	8. 000	9. 446906	11
11	74. 228	74. 228	446. 086	86. 787	3. 000	3. 000	8. 000	8. 000	9. 602143	11
12	66. 416	66. 416	413. 483	97. 411	3. 000	3. 000	8. 000	8. 000	9. 747416	10
13	66. 322	66. 322	417. 960	99. 185	3. 000	3. 000	8. 000	8. 000	9. 883102	10
14	66. 211	66. 211	422. 385	100. 983	3. 000	3. 000	8. 000	8. 000	10. 016350	10
15	66. 085	66. 085	426. 739	102. 804	3. 000	3. 000	8. 000	8. 000	10. 147783	10
16	65. 944	65. 944	431. 083	104. 646	3. 000	3. 000	8. 000	8. 000	10. 276826	10
17	65. 790	65. 790	435. 337	106. 310	3. 000	3. 000	8. 000	8. 000	10. 403703	10
18	65. 624	65. 624	439. 584	108. 394	3. 000	3. 000	8. 000	8. 000	10. 528449	10
19	58. 461	58. 461	410. 792	119. 723	3. 000	3. 000	8. 000	8. 000	10. 644824	9
20	58. 325	58. 325	414. 408	121. 921	3. 000	3. 000	8. 000	8. 000	10. 733151	9
21	58. 182	58. 182	417. 999	123. 334	3. 000	3. 000	8. 000	8. 000	10. 859826	9
22	58. 032	58. 032	421. 564	123. 163	3. 000	3. 000	8. 000	8. 000	10. 964869	9
23	57. 875	57. 875	429. 104	127. 007	3. 000	3. 000	8. 000	8. 000	11. 068300	9
24	57. 712	57. 712	428. 618	128. 864	3. 000	3. 000	8. 000	8. 000	11. 170137	9
25	57. 543	57. 543	432. 109	130. 737	3. 000	3. 000	8. 000	8. 000	11. 270402	9
26	57. 369	57. 369	435. 373	132. 622	3. 000	3. 000	8. 000	8. 000	11. 367113	9
27	57. 167	57. 167	439. 174	134. 580	3. 000	3. 000	8. 000	8. 000	11. 466284	9
28	56. 984	56. 984	442. 583	136. 490	3. 000	3. 000	8. 000	8. 000	11. 561871	9
29	56. 797	56. 797	445. 974	138. 412	3. 000	3. 000	8. 000	8. 000	11. 655989	9
30	56. 606	56. 606	449. 341	140. 347	3. 000	3. 000	8. 000	8. 000	11. 748400	9
31	50. 107	50. 107	423. 276	152. 680	3. 000	3. 000	8. 000	8. 000	11. 834674	8
32	49. 938	49. 938	426. 199	154. 477	3. 000	3. 000	8. 000	8. 000	11. 914440	8
33	49. 807	49. 807	429. 111	156. 263	3. 000	3. 000	8. 000	8. 000	11. 993099	8
34	49. 633	49. 633	432. 010	158. 098	3. 000	3. 000	8. 000	8. 000	12. 070463	8
35	49. 497	49. 497	434. 898	159. 922	3. 000	3. 000	8. 000	8. 000	12. 147147	8
36	49. 339	49. 339	437. 774	161. 754	3. 000	3. 000	8. 000	8. 000	12. 222365	8
37	49. 179	49. 179	440. 639	163. 593	3. 000	3. 000	8. 000	8. 000	12. 296930	8
38	49. 018	49. 018	443. 493	165. 445	3. 000	3. 000	8. 000	8. 000	12. 370296	8
39	48. 855	48. 855	446. 336	167. 303	3. 000	3. 000	8. 000	8. 000	12. 442996	8
40	48. 690	48. 690	449. 168	169. 169	3. 000	3. 000	8. 000	8. 000	12. 513844	8
41	48. 524	48. 524	451. 991	171. 043	3. 000	3. 000	8. 000	8. 000	12. 584134	8
42	48. 357	48. 357	454. 803	172. 925	3. 000	3. 000	8. 000	8. 000	12. 653439	8
43	48. 188	48. 188	457. 604	174. 815	3. 000	3. 000	8. 000	8. 000	12. 721771	8
44	48. 019	48. 019	460. 397	176. 713	3. 000	3. 000	8. 000	8. 000	12. 789146	8
45	47. 848	47. 848	463. 180	178. 618	3. 000	3. 000	8. 000	8. 000	12. 853375	8
46	47. 677	47. 677	465. 953	180. 531	3. 000	3. 000	8. 000	8. 000	12. 921071	8
47	47. 503	47. 503	468. 717	182. 450	3. 000	3. 000	8. 000	8. 000	12. 985649	8
48	47. 332	47. 332	471. 472	184. 377	3. 000	3. 000	8. 000	8. 000	13. 049320	8
49	47. 158	47. 158	474. 219	186. 311	3. 000	3. 000	8. 000	8. 000	13. 112097	8
50	46. 984	46. 984	476. 937	188. 293	3. 000	3. 000	8. 000	8. 000	13. 173994	8
51	46. 809	46. 809	479. 687	190. 201	3. 000	3. 000	8. 000	8. 000	13. 235022	8
52	46. 634	46. 634	482. 408	192. 155	3. 000	3. 000	8. 000	8. 000	13. 295194	8

SYSTEM SUMMARY--&gt;&gt;

LINEAR, LONG, PARAMS-&gt;

NT MUL GAML BETAL  
1 19. 975 .042 24. 081  
2 19. 975 .042 24. 081

q1 .vnqtnUCLPI'GG1`TBqq1`.....pnqqxKLNSR`.... jj END OF LISTING jj ..eeeeeee.. eeee

NT	XHUT	YHUT	BETAX	BETAY	HP1	HP2	GLA	GLB	CELL	NC
1	76.769	76.769	387.294	83.710	3.023	2.466	8.000	8.000	B. 507639	12
2	131.024	131.024	578.481	26.065	2.466	3.478	8.000	8.000	B. 507639	12
3	126.348	126.348	538.877	29.071	3.478	3.418	8.000	8.000	B. 507639	12
4	109.661	109.661	443.042	42.216	3.418	3.150	8.000	8.000	B. 507639	12
5	67.010	68.481	466.023	99.889	2.647	2.682	8.000	8.000	B. 602370	12
6	69.645	74.048	466.037	99.819	2.689	2.702	8.000	8.000	B. 788981	12
7	57.983	55.876	465.948	100.375	2.629	2.779	8.000	8.000	B. 963991	11
8	59.307	58.542	465.941	100.265	2.657	2.800	8.000	8.000	B. 127860	11
9	61.053	58.936	465.962	100.296	2.687	2.820	8.000	8.000	B. 288822	11
10	62.674	61.422	465.961	100.206	2.719	2.843	8.000	8.000	B. 446906	11
11	64.335	61.718	465.983	100.235	2.753	2.864	8.000	8.000	B. 602145	11
12	53.821	50.196	465.851	101.140	2.710	2.954	8.000	8.000	B. 747416	10
13	54.840	50.479	465.865	101.189	2.735	2.976	8.000	8.000	B. 983102	10
14	55.907	52.554	465.861	100.982	2.763	3.001	8.000	8.000	B. 016350	10
15	56.951	52.770	465.877	101.030	2.790	3.024	8.000	8.000	B. 147783	10
16	58.044	54.730	465.875	100.859	2.819	3.049	8.000	8.000	B. 276682	10
17	59.118	54.888	465.893	100.906	2.849	3.073	8.000	8.000	B. 403705	10
18	60.245	56.749	465.893	100.761	2.881	3.099	8.000	8.000	B. 528445	10
19	50.238	48.866	465.722	102.405	2.850	3.199	8.000	8.000	B. 644624	9
20	50.971	46.522	465.725	102.063	2.876	3.227	8.000	8.000	B. 733151	9
21	51.659	46.642	465.734	102.144	2.900	3.251	8.000	8.000	B. 899826	9
22	52.349	46.751	465.745	102.206	2.925	3.274	8.000	8.000	B. 964869	9
23	53.084	48.306	465.748	101.930	2.953	3.303	8.000	8.000	B. 068300	9
24	53.776	48.381	465.759	101.990	2.979	3.327	8.000	8.000	B. 170137	9
25	54.470	48.449	465.773	102.052	3.003	3.351	8.000	8.000	B. 270402	9
26	55.211	49.918	465.775	101.810	3.035	3.379	8.000	8.000	B. 369113	9
27	55.922	49.930	465.790	101.874	3.064	3.404	8.000	8.000	B. 466284	9
28	56.666	51.345	465.792	101.661	3.094	3.433	8.000	8.000	B. 561871	9
29	57.371	51.359	465.807	101.717	3.123	3.458	8.000	8.000	B. 655969	9
30	58.120	52.723	465.810	101.529	3.155	3.486	8.000	8.000	B. 748600	9
31	47.957	42.143	465.581	103.512	3.131	3.608	8.000	8.000	B. 824674	8
32	48.395	42.172	465.585	103.584	3.154	3.632	8.000	8.000	B. 914440	8
33	48.881	43.366	465.593	103.235	3.181	3.663	8.000	8.000	B. 993099	8
34	49.317	43.378	465.598	103.305	3.205	3.687	8.000	8.000	B. 070663	8
35	49.751	43.386	465.603	103.375	3.229	3.711	8.000	8.000	B. 147147	8
36	50.230	44.530	465.612	103.062	3.256	3.742	8.000	8.000	B. 222265	8
37	50.661	44.522	465.618	103.130	3.281	3.766	8.000	8.000	B. 296930	8
38	51.090	44.512	465.625	103.199	3.305	3.790	8.000	8.000	B. 370256	8
39	51.564	45.610	465.632	102.914	3.333	3.821	8.000	8.000	B. 442556	8
40	51.990	45.586	465.640	102.981	3.359	3.845	8.000	8.000	B. 513844	8
41	52.415	45.559	465.648	103.048	3.384	3.870	8.000	8.000	B. 584134	8
42	52.884	46.617	465.655	102.788	3.413	3.900	8.000	8.000	B. 653439	8
43	53.306	46.577	465.663	102.852	3.439	3.925	8.000	8.000	B. 721771	8
44	53.727	46.536	465.672	102.917	3.465	3.950	8.000	8.000	B. 789146	8
45	54.191	47.556	465.678	102.677	3.495	3.980	8.000	8.000	B. 835575	8
46	54.610	47.503	465.687	102.740	3.522	4.005	8.000	8.000	B. 921071	8
47	55.070	48.498	465.693	102.520	3.552	4.034	8.000	8.000	B. 985649	8
48	55.487	48.435	465.703	102.581	3.579	4.061	8.000	8.000	B. 049320	8
49	55.902	48.370	465.713	102.641	3.607	4.086	8.000	8.000	B. 112097	8
50	56.360	49.333	465.718	102.437	3.637	4.116	8.000	8.000	B. 173994	8
51	56.774	49.259	465.728	102.495	3.666	4.141	8.000	8.000	B. 233022	8
52	57.228	50.200	465.733	102.306	3.697	4.171	8.000	8.000	B. 295194	8

SYSTEM. SUMMARY--&gt;&gt;

15. 13. 33. UCLP. CG. TB11.

0. 114KLNS.

\*\* END OF LISTING \*\*

PREC= 800.000, PGEEXT= 2.00, ICHRON= 1,  
 XPN= 15.00, XPTW= 15.0, YPN= 15.0, DPM= 30.0, DMP= 3000.0, DPP= 30.0,  
 M1= 1.100-240, MAX= 10.0, PGMAX= 2.0,  
 NT( 1)= 3.A(1, 1)= -36.23 0 , 40.00  
 NT( 2)= 1.A(1, 2)= 2.537  
 NT( 3)= 13.A(1, 3)= .8112 1021. -90.00 , 12.00  
 NT( 4)= 1.A(1, 4)= 2.537  
 NT( 5)= 3.A(1, 5)= 24.42 40.00  
 NT( 6)= 3.A(1, 6)= 24.44 40.00  
 NT( 7)= 1.A(1, 7)= 2.539  
 NT( 8)= 13.A(1, 8)= .8112 1021. -90.00 , 12.00  
 NT( 9)= 1.A(1, 9)= 2.539  
 NT( 10)= 3.A(1, 10)= -37.44 40.00  
 NT( 11)= 3.A(1, 11)= -34.78 40.00  
 NT( 12)= 1.A(1, 12)= 2.539  
 NT( 13)= 13.A(1, 13)= .8112 1021. -90.00 , 12.00 , 11  
 NT( 14)= 1.A(1, 14)= 2.539  
 NT( 15)= 3.A(1, 15)= 31.35 40.00  
 NT( 16)= 3.A(1, 16)= 34.18 40.00  
 NT( 17)= 1.A(1, 17)= 2.539  
 NT( 18)= 13.A(1, 18)= .8112 1021. -90.00 , 12.00 , 116  
 NT( 19)= 1.A(1, 19)= 2.539  
 NT( 20)= 3.A(1, 20)= -34.20 40.00  
 NT( 21)= 3.A(1, 21)= -26.47 40.00  
 NT( 22)= 1.A(1, 22)= 2.539  
 NT( 23)= 13.A(1, 23)= 4.904 1032. -32.06 , 12.00 , 122.  
 NT( 24)= 1.A(1, 24)= 3.481  
 NT( 25)= 3.A(1, 25)= 24.82 40.00  
 NT( 26)= 3.A(1, 26)= 24.87 40.00  
 NT( 27)= 1.A(1, 27)= 3.481  
 NT( 28)= 13.A(1, 28)= 4.904 1033. -32.06 , 12.00 , 129.26  
 NT( 29)= 1.A(1, 29)= 4.405  
 NT( 30)= 3.A(1, 30)= -27.02 40.00  
 NT( 31)= 3.A(1, 31)= -26.29 40.00  
 NT( 32)= 1.A(1, 32)= 4.405  
 NT( 33)= 13.A(1, 33)= 5.904 986.0 -32.05 , 11.00 , 135.2216  
 NT( 34)= 1.A(1, 34)= 5.232  
 NT( 35)= 3.A(1, 35)= -27.79 40.00  
 NT( 36)= 3.A(1, 36)= 26.37 40.00  
 NT( 37)= 1.A(1, 37)= 5.232  
 NT( 38)= 13.A(1, 38)= 5.904 1004. -32.05 , 11.00 , 141.2769  
 NT( 39)= 1.A(1, 39)= 5.044  
 NT( 40)= 3.A(1, 40)= -26.00 40.00  
 NT( 41)= 3.A(1, 41)= -26.87 40.00  
 NT( 42)= 1.A(1, 42)= 5.044  
 NT( 43)= 13.A(1, 43)= 6.904 1022. -32.05 , 11.00 , 147.4544  
 NT( 44)= 1.A(1, 44)= 6.842  
 NT( 45)= 3.A(1, 45)= -28.20 40.00  
 NT( 46)= 3.A(1, 46)= -27.19 40.00  
 NT( 47)= 1.A(1, 47)= 6.842  
 NT( 48)= 13.A(1, 48)= 6.904 1039. -32.05 , 11.00 , 153.7036  
 NT( 49)= 1.A(1, 49)= 7.625  
 NT( 50)= 3.A(1, 50)= -28.43 40.00  
 NT( 51)= 3.A(1, 51)= -27.33 40.00  
 NT( 52)= 1.A(1, 52)= 7.625  
 NT( 53)= 13.A(1, 53)= 6.904 1056. -32.05 , 11.00 , 160.0456  
 NT( 54)= 1.A(1, 54)= 8.394  
 NT( 55)= 3.A(1, 55)= -28.44 40.00  
 NT( 56)= 3.A(1, 56)= -27.30 40.00  
 NT( 57)= 1.A(1, 57)= 8.394  
 NT( 58)= 13.A(1, 58)= 6.904 974.7 -32.04 , 10.00 , 163.8799  
 NT( 59)= 1.A(1, 59)= 9.078

eg → TRACEx DATA - Set